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ARMAMENT SYSTEMS, INC.

3 February 1987

Director
US Army Laboratory Command
Human Engineering Laboratory
ATTN: SLCHE-CS (Mr. John D. Waugh)
Aberdeen Proving Ground, MD 21005-5001

Dear Mr. Waugh:

Attached is ASI Report 86-03, "Ammunition Reconfiguration Module Operating Characteristics and Rates". This task satisfies the requirements on Task Order Number 4, Contract DAAK11-84-D-0004.

ASI has enjoyed this opportunity to work with you on this project.

Sincerely,

B M Davall

B. M. DAVALL
Group Vice President

BMD/amc

Enclosure: A/S

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PREFACE

In an earlier research study report entitled: "Wargaming Analysis of Ammunition Flow Rates", Armament Systems, Inc., (ASI) developed a series of detailed matrices which portrayed daily ammunition expenditure rates for eleven different combat battalion sized units. Rates were provided for both high intensity and mid-intensity scenarios. The battalion data were then grouped into ten different brigade configurations and expenditure data summarized for each mix of units engaged in high and mid-intensity conflicts. The final part of the report examined the available unit vehicles used for the transport of ammunition and, based on vehicle capacities, the number of ammunition convoys per 24 hour period required to transport the ammunition for each type unit was developed for each scenario. This effort provided the necessary technical base information for performance of this follow-on task entitled "Ammunition Reconfiguration Module Operating Characteristics and Rates". JBS

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I INTRODUCTION AND BACKGROUND

For the past three or more years, the U.S. Army Human Engineering Laboratory (USAHEL) has been doing extensive technical base work in the development and expansion of a new concept for ammunition resupply. This concept, which utilizes in-theater repackaging of ammunition, is intended to support the AirLand Battle and the transition to Army 21. It represents the first significant attempt to introduce high technology into the Army's battlefield logistical system. During this period, significant analytical work has been done in looking at the flow rates through the major component within the concept, the "Ammunition Reconfiguration Module (ARM)". The studies have looked at the flow rates of ammunition through the ARM as a function of the intensity of the battle scenarios.

Advanced research toward the development of robotic, autonomous and semi-autonomous submodules for the unloading, sorting, unpackaging, repackaging and uploading of ammunition is being undertaken by various materiel development agencies. In order to develop the submodules with the proper operating characteristics, it will be necessary to thoroughly examine the detailed flow rates of ammunition through each of the four planned submodules within the ARM. Since the major function of the ARM submodules is to reconfigure ammunition from it's current wholesale logistical pack into a battlefield pack, and since this equipment will be primarily robotic, it is mandatory that a well defined operating characteristics envelope be developed.

II OBJECTIVE

The objective of this work effort is to examine the flow rates of ammunition through each of the four submodules of the Ammunition Reconfiguration Module to develop the envelope of operating characteristics for each of these submodules that will provide the required amount of ammunition to meet the predicted threat. (NOTE: As indicated in the preface, the analytical effort described in this task is based on the results of the previously completed study entitled "Wargaming Analysis of Ammunition Flow Rates").

III STATEMENT OF WORK

In order to carry out the above stated objective, the following subtasks were established.

a. Identify the appropriate mixes of ammunition that will be stored and issued from the ARM by generic type and quantity. Within these mixes, identify those types of ammunition which must not be reconfigured from today's logistical pack to a tactical package.

> NOTE: It will be assumed that the logistical (wholesale) packaging of all ammunition is done as it is today.

b. Identify by type and quantity, the ammunition which will be repalletized into a mixed load but will not be reconfigured from it's basic packaging.

c. Identify by type and quantity, that ammunition which will be issued in the same configuration in which it is received (no repalletizing or reconfiguring required).

d. For the ammunition which requires reconfiguring, identify the flow rate through each of the ARM submodules in order to meet the expected demand. This shall include an analysis of the transfer of the ammunition from the submodule, and back to the output storage buffer.

e. Identify the quantity and breakdown (wood, steel, etc.) of scrap material that will be generated during the reconfiguring of ammunition packages.

f. For each of the four submodules of the ARM, analyze the required flow rates and prescribe the operating envelope that will be the goal of the engineering development for each of these submodules. All analytical effort required shall be included in the documentation.

IV DISCUSSION

A. Ammunition to be Stored and Issued From the ARM

As indicated above, the first subtask requires the identification of the appropriate mixes of ammunition that will be stored and issued from the ARM by generic type and quantity.

For this analysis it is assumed that a division will be supported by four Ammunition Reconfiguration Modules (ARM) which is the successor to the ASP and four ammunition transfer points (ATP's). One ARM and one ATP will be dedicated to each of the division's three brigades. The fourth ARM/ATP will supply ammunition to the divisional and General Support (GS) units. Table 1 shows that the demand on a ARM for a 24 hour period based on a mid-intensity scenario for one brigade of a heavy division is approximately 1500 Short Tons (ST). (The total demand is 1740 ST. The ATP issues 300 ST to the brigade, but the arm issues 60 of these ST to the ATP). Note that this particular brigade has three tank, two mechanized infantry, and one 155mm Howitzer battalion plus an air defense battery and an engineer company. The demand generated by this brigade is representative of a "typical" brigade in an armored division. The demand generated by a specific brigade in a specific scenario is a function of the number of tank and mechanized infantry battalions (which can vary from two to seven) assigned to the brigade. Other studies have shown that the daily tonnage demand for a brigade can vary from 1100 to 1900 ST per day. However, in this study, only one brigade structure will be used, but the effect of ± 20% variation in the demand will be examined. These demands are identified by generic type and quantity in Table 1. Items identified with one asterisk represent those types of ammunition which must be reconfigured from today's logistical (wholesale) pack to a "near bare round" tactical package.

Table 1 - Demand on ASP/ARM (1500 ST/24 Hours) (Mid Intensity Scenario)								
	Tank - 3 Bns.	Mech. - 2 Bns.	Arty - 1 Bn.	ADA - 1 Btry.	Engr - 1 Co.	ATP	TOTAL	% of TOTAL
155 mm Proj*	0.00	0.00	459.26	0.00	0.00	27.62	486.88	32.46%
155 mm Prop	0.00	0.00	187.53	0.00	0.00	12.28	199.81	13.32%
105 mm*	344.93	0.00	0.00	0.00	0.00	21.48	366.41	24.43%
4.2 in*	130.01	86.68	0.00	0.00	0.00	0.00	216.69	14.45%
TOW	10.50	49.72	0.00	0.00	0.00	0.00	60.22	4.01%
DRAGON	0.00	17.19	0.00	0.00	0.00	0.00	17.19	1.15%
STINGER	0.00	0.00	0.00	6.02	0.00	0.00	6.02	0.40%
66 mm	1.84	2.70	0.00	0.00	0.00	0.00	4.54	0.30%
40 mm ADA	0.00	0.00	0.00	18.46	0.00	0.00	18.46	1.23%
40 mm Gren	0.37	1.96	0.53	0.20	0.02	0.00	3.09	0.21%
40 mm Smk	25.05	19.15	1.06	0.00	2.45	0.00	47.71	3.18%
25 mm	0.37	22.53	0.00	0.00	0.00	0.00	22.90	1.53%
.50 cal	14.73	2.03	1.06	0.65	0.93	0.00	19.41	1.29%
.45 cal	0.09	0.02	0.00	0.00	0.00	0.00	0.11	0.01%
7.62 mm	17.31	1.90	0.13	0.16	0.02	0.00	19.53	1.30%
5.56 mm	1.47	7.24	1.20	0.65	0.47	0.00	11.04	0.74%
TOTAL	546.67	211.13	650.78	26.15	3.89	61.39	1500.00	100.00%
% of TOTAL	36.44%	14.08%	43.39%	1.74%	0.26%	4.09%	100.00%	
* - Requires Reconfiguration								

Tables 2 and 3 provide similar information based on factors of 1200 and 1800 ST per 24 hour period (± 20%).

Table 2 - Demand on ASP/ARM (1200 ST/24 Hours) (Mid Intensity Scenario)								
	Tank - 3 Bns.	Mech. - 2 Bns.	Arty - 1 Bn.	ADA - 1 Btry.	Engr - 1 Co.	ATP	TOTAL	% of TOTAL
155 mm Proj	0.00	0.00	367.41	0.00	0.00	22.10	389.50	32.46%
155 mm Prop	0.00	0.00	150.03	0.00	0.00	9.82	159.85	13.32%
105 mm	275.94	0.00	0.00	0.00	0.00	17.19	293.13	24.43%
4.2 in	104.01	69.34	0.00	0.00	0.00	0.00	173.35	14.45%
TOW	8.40	39.78	0.00	0.00	0.00	0.00	48.18	4.01%
DRAGON	0.00	13.75	0.00	0.00	0.00	0.00	13.75	1.15%
STINGER	0.00	0.00	0.00	4.81	0.00	0.00	4.81	0.40%
66 mm	1.47	2.16	0.00	0.00	0.00	0.00	3.63	0.30%
40 mm ADA	0.00	0.00	0.00	14.77	0.00	0.00	14.77	1.23%
40 mm Gren	0.29	1.57	0.43	0.16	0.02	0.00	2.47	0.21%
40 mm Smk	20.04	15.32	0.85	0.00	1.96	0.00	38.17	3.18%
25 mm	0.29	18.02	0.00	0.00	0.00	0.00	18.32	1.53%
.50 cal	11.79	1.62	0.85	0.52	0.74	0.00	15.53	1.29%
.45 cal	0.07	0.02	0.00	0.00	0.00	0.00	0.09	0.01%
7.62 mm	13.85	1.52	0.11	0.13	0.02	0.00	15.62	1.30%
5.56 mm	1.18	5.79	0.96	0.52	0.38	0.00	8.83	0.74%
TOTAL	437.34	168.90	520.62	20.92	3.11	49.11	1200.00	100.00%
% of TOTAL	36.44%	14.08%	43.39%	1.74%	0.26%	4.09%	100.00%	

Table 3 - Demand on ASP/ARM (1800 ST/24 Hours) (Mid Intensity Scenario)	Tank - 3 Bns.	Mech. - 2 Bns.	Arty - 1 Bn.	ADA - 1 Btry.	Engr - 1 Co.	ATP	TOTAL	% of TOTAL
155 mm Proj	0.00	0.00	551.11	0.00	0.00	33.15	584.26	32.46%
155 mm Prop	0.00	0.00	225.04	0.00	0.00	14.73	239.77	13.32%
105 mm	413.91	0.00	0.00	0.00	0.00	25.78	439.69	24.43%
4.2 in	156.02	104.01	0.00	0.00	0.00	0.00	260.03	14.45%
TOW	12.60	59.67	0.00	0.00	0.00	0.00	72.26	4.01%
DRAGON	0.00	20.63	0.00	0.00	0.00	0.00	20.63	1.15%
STINGER	0.00	0.00	0.00	7.22	0.00	0.00	7.22	0.40%
66 mm	2.21	3.24	0.00	0.00	0.00	0.00	5.45	0.30%
40 mm ADA	0.00	0.00	0.00	22.15	0.00	0.00	22.15	1.23%
40 mm Gren	0.44	2.36	0.64	0.25	0.02	0.00	3.71	0.21%
40 mm Smk	30.05	22.98	1.28	0.00	2.93	0.00	57.25	3.18%
25 mm	0.44	27.03	0.00	0.00	0.00	0.00	27.48	1.53%
.50 cal	17.68	2.43	1.28	0.79	1.12	0.00	23.29	1.29%
.45 cal	0.11	0.02	0.00	0.00	0.00	0.00	0.14	0.01%
7.62 mm	20.77	2.28	0.16	0.20	0.02	0.00	23.44	1.30%
5.56 mm	1.77	8.69	1.44	0.79	0.56	0.00	13.25	0.74%
TOTAL	656.00	253.35	780.94	31.38	4.67	73.66	1800.00	100.00%
% of TOTAL	36.44%	14.08%	43.39%	1.74%	0.26%	4.09%	100.00%	

It should be noted that approximately 20% of the ammunition issued by an ATP is processed through an ASP/ARM. (The remainder comes via direct throughput from a Corps storage area (CSA)). These items are the high tonnage, high usage items and are normally those same type items that require reconfiguring from a logistical (wholesale) package to a tactical package. In this study it is assumed that the ATP will issue 300 ST per day and will stock only 105mm tank and 155mm artillery ammunition. Of the 300 ST, 60 ST will be provided by the ASP/ARM. (NOTE: A division commander may identify other high tonnage, high density items that he desires to be issued from the ATP such as the TOW missiles). As shown in Table 1, three such items, the 155mm projectile and the propellent charge and, the 105mm tank round represent 70.2% of the total daily tonnages of ammunition flowing through an ASP/ARM.

B. Ammunition to be Repalletized into a Mixed Load But Not Reconfigured From It's Basic Packaging

Subtask "b" requires the identification of ammunition by type and quantity which will be repalletized into a "mixed pallet" but will not be reconfigured from it original basic wholesale type packaging. Generally, these types of ammunition are those items in which a company sized unit's daily demands are less than a full pallet of each type round. The objective of a "mixed pallet" is to provide a pallet with boxes of the various types of ammunition (usually consisting of the smaller caliber ammunition, grenades and pyrotechnics) to meet a type company's needs for a 24 hour period. If a maneuver battalion is picking up ammunition for it's lettered companies twice a day, then a mixed pallet should ideally be configured to meet a half-day's requirement for the company because of the limited storage capability within the company.

The "Mixed Pallet" concept offers two major advantages. First, it significantly reduces the time and labor requirements at the unit level. Under the current system, a battalion picks up full pallets of a single type ammunition at the ASP. A battalion ammunition convoy may have part of the ammunition required by each company on each vehicle. This means that either the ammunition must be unloaded at the battalion trains area and broken down into the requirements for each company and then uploaded for movement to each of the three lettered companies, or all of the battalion ammunition resupply vehicles must sequentially visit each of the three company areas and off-load the required mix of ammunition. Either method is time consuming and labor intensive.

Under the "mixed pallet" concept, a mixed pallet containing the types and quantities of each type of ammunition required by each company is picked up at the ASP/ARM together with the full pallet quantities of the other types of ammunition required by each company. Each truck is loaded with a company sized load so that one truck each proceeds simultaneously to each of the three lettered line companies. This avoids the delays in the battalion trains reducing both time and labor at the unit level where labor and time are both critical. (See ASI Report: "HELFAST II Testing--Assembly of Unit Configured Loads from an Armored Battalion Configured Field Storage Unit", dated March 1985 for further information on the Unit Configured Load of which the mixed pallet is a part).

The second major advantage of the "mixed pallet" is that it can be configured ahead of time at the ASP/ARM where skilled labor and materiel handling equipment are available. This significantly reduces the time a battalion vehicle is at an ASP/ARM picking up it's required ammunition. As one pallet provides the ammunition previously stored at several field storage units (FSU's).

Using the same brigade structure as shown in Table 1 and based on a mid-intensity wargame scenario, an analysis was made of the quantities and types of ammunition that would be required by each type unit within the brigade structure which could most appropriately be included in a mixed pallet for each lettered company within the battalion. This information is shown in Table 4.

Based on the information shown in Table 4, it can be concluded that:

a. It is feasible to issue one mixed pallet per day to an M1 tank company containing the following:

2 Boxes 40mm Grenades
12 boxes 40 smoke Grenades, M257
21 Boxes 40mm Smoke Grenades, M239
8 Boxes 40mm Smoke Grenades, M259
2 Boxes 25mm Linked
5 Boxes 5.56mm Ball.

b. It is feasible to issue one mixed pallet of ammunition per day to an M60 tank company containing the following:

2 Boxes 40mm Rifle Grenades
15 Boxes 40mm Grenades, Smoke M257
8 Boxes 40mm Grenades, Smoke M259
2 Boxes 25mm Linked
5 Boxes 5.56mm Ball.

Table 4 - Typical Mixed Pallet Configurations By Type Battalion
(Ammunition Expended In a 24-Hour Period)

Type Ammo.	Weapon	No. Rds Expended by ea. company	No. Rds per pack	No. packs per pallet	No. packs per day per co.	Total pallets	Total tons
M1 Tank Co							
40mm Rfl Gren	Rifle	70	50	36	1.4 = 2	.04	.04
40mm Smoke	Gren, M257	48	4	99	12.0 = 12	.12	.15
40mm Smoke	Gren, M239	84	4	99	21.0 = 21	.21	.27
40mm Smoke	Gren, M259	32	4	99	8.0 = 8	.08	.10
25mm	CFV	40	30	30	1.3 = 2	.04	.03
5.56mm Ball	Rifle	7450	1640	48	4.5 = 5	.09	.13
						.58	.72 (1440 lbs)
M60 Tank Co							
40mm Rfl Gren	Rifle	70	50	36	1.4 = 2	.04	.04
40mm Smoke	Gren, M257	58	4	99	14.5 = 15	.14	.18
40mm Smoke	Gren, M259	32	4	99	8.0 = 8	.08	.10
25mm	CFV	40	30	30	1.3 = 2	.04	.03
5.56mm Ball	Rifle	6750	1640	48	4.1 = 5	.09	.15
						.39	.50 (1900 lbs)
Mech Inf Co W/BFVS							
40mm Rfl Gren	Rifle	565	50	36	11.3 = 12	.31	.32
40mm Smoke	Gren, M259	168	4	99	42.0 = 42	.42	.53
40mm Smoke	Gren, M243	96	4	99	24.0 = 24	24	.30
40mm Smoke	Gren, M239	84	4	99	21.0 = 21	.21	.27
7.62mm Ball	Machine Gun	6240	800	48	7.8 = 8	16	31
50 Cal Ball	M113 & M107	1387	200	48	6.9 = 7	.18	.33
						1.52	2.06 (4120 lbs)
Mech Inf Co W/M113							
40mm Rfl Gren	Rifle	645	50	36	12.9 = 13	.36	.36
40mm Smoke	Gren, M243	316	4	99	79.0 = 79	.80	1.00
40mm Smoke	Gren, M259	312	4	99	78.0 = 78	.79	.98
40mm Smoke	Gren, M239	9	4	99	2.3 = 3	.03	04
7.62mm Ball	Machine Gun	5733	800	48	7.2 = 8	.15	.28
5.56mm Ball	SAW/Rifle	21619	1640	48	13.2 = 14	27	43
						2.40	3.09 (6180 lbs)
155mm SP FA Bn							
40mm Rfl Gren	Rifle	270	50	36	5.4 = 6	.15	.15
40mm Smoke	Gren, M243	104	4	99	2.6 = 3	.26	.33
50 Cal Ball	Machine Gun	1792	200	48	8.9 = 9	.19	.34
7.62mm Ball	Machine Gun	920	800	48	1.2 = 2	.02	.05
5.56mm Ball	Rifle	17200	1640	48	10.5 = 11	.22	.37
						.84	1.24 (2480 lbs)
SP ADA Btry							
40mm Rfl Gren	Rifle	330	50	36	6.6 = 7	.18	.18
40mm Smoke	Gren, M259	192	4	99	48.0 = 48	.48	.61
50 Cal Ball	Machine Gun	3307	200	48	16.5 = 17	.34	.64
5.56mm Ball	SAW/Rifle	27148	1640	48	16.6 = 17	.42	.64
Engr. Co							
5.56mm Ball	SAW/Rifle	26684	1640	48	16.3 = 17	.40	.61
7.62mm Ball	Machine Gun	427	800	48	.5 = 1	.01	.02
40mm Rfl Gren	Rifle	50	50	36	1.0 = 1	08	08
50 Cal Ball	Machine Gun	6293	200	48	31.5 = 32	.66	1.21
						1 15	1.92 (3840 lbs)

c. It is feasible to issue two mixed pallets per day to a mechanized infantry company equipped with Bradley Fighting Vehicles. Pallets should consist of the following:

6 Boxes 40mm Rifle Grenades
31 Boxes 40mm Smoke Grenades, M259
12 Boxes 40mm Smoke Grenades, M243
11 Boxes 40mm Smoke Grenades, M239
4 Boxes 7.62mm Ball ammunition
4 Boxes 50 Cal Ball ammunition.

d. It is feasible to issue 2 mixed pallets per day to a mechanized infantry company equipped with M113 APCs. Pallets should consist of the following:

7 Boxes 40mm Rifle Grenades
40 Boxes 40mm Smoke Grenades, M243
39 Boxes 40mm Smoke Grenades, M259
2 Boxes 40mm Smoke Grenades, M239
4 Boxes 50 Cal Ball
7 Boxes 5.56mm Ball.

e. It is feasible to issue one mixed pallet of ammunition per day to a 155mm self-propelled field artillery battery consisting of the following:

6 Boxes 40mm Rifle Grenades
3 Boxes 40mm Smoke Grenades, M243
9 Boxes 50 Cal Ball
2 Boxes 7.62mm Ball
11 Boxes 5.56mm Ball.

f. It is feasible to issue two mixed pallets of small arms ammunition to a self-propelled air defense artillery battery each day consisting of the following:

4 Boxes 40mm Rifle Grenades
24 Boxes 40mm Smoke Grenades, M259
9 Boxes 50 Cal Ball
9 Boxes 5.56mm Ball.

g. An engineer company demand for small arms ammunition exclusive of 50 cal ball is too small for a mixed pallet each day and too large when the 50 cal requirements are added. It is therefore not feasible to preconfigure and issue mixed pallets of small arms ammunition to an engineer company.

NOTE: The authors are aware of the actual test assembly of only one configuration of a mixed pallet of ammunition. Although the above listed mixed pallets are reasonable in terms of total weight, it is recommended that limited field trails be conducted to determine the best arrangements of the various boxes on a pallet to check the cube for each mix and the integrity of a pallet containing boxes of several types and dimensions.

C. Ammunition Flow Rates Through and Operating Envelopes For The ARM Robotic Submodules

Subtask "d" calls for an identification of the flow rates of ammunition through each of the ARM submodules in order to meet the expected demand. This includes an analysis of the transfer of the ammunition from the unload submodule to the input storage buffer; back to the reconfiguration submodule; and back to the output storage buffer. Subtask "f" is similar in that it requires an analysis of the flow rates and the operating envelope for each of the submodules.

1. Download Submodule - The function of the download submodule is to rapidly and automatically unload palletized ammunition from the bed of a transportation long-haul vehicle onto a platform in the ARM so it can be sorted for further processing. The long-haul vehicles will normally be either a 22 1/2 ST, a 34 ST stake and platform (S&P) semi-trailer or Palletized Loading System (PLS) flat racks. The palletized ammunition may be in a container in which case a slipsheet will be used to pull the ammunition out of the container on to a working platform (See Figure 1), or it will be located directly on the flatbed of the semi-trailer or PLS (See Figure 2). As shown in the schematics of Figures 1 and 2, the operating envelope for the downloading submodule can be a 25 ft. radius for the manipulator arm and end effector with 360° operating circle. This permits the unloading of palletized ammunition directly from a long-haul vehicle, MILVAN, ISO container and/or PLS platform onto a conveyor.

The rate at which the downloading submodule is to operate is dictated by the TRADOC requirement that an ARM be functional, i.e., capable of supplying ammunition to customers, within two hours of arrival at a new site. In order to have the required amount of ammunition ready for issue within this two hour period, the downloading submodule requires an average operating cycle time of 20 seconds per lift.

The average pallet of ammunition that will be processed through the downloader weighs approximately 1223 pounds. However, since 155mm projectiles are usually shipped with three pallets banded together, the average lift is 2188 pounds. for each cycle of the downloader. Based on a total of 1070 ST of ammunition to be loaded and reconfigured each 24 hour period, 982 unload cycles would be required, assuming one pallet of either 105mm, 4.2 inch or three pallets of 155mm projectiles would be downloaded on each cycle of the downloader. With a cycle rate of 20 seconds, 5.45 hours would be required to download the 1070 ST. During a surge operation, when the daily tonnages could be expected to increase to 1284 ST, the time to download would climb to 6.54 hours. These times assume a continuous, uninterrupted operation. Obviously, in an ARM, delays can be expected to occur, for example, as vehicles are positioned alongside the downloading submodule for unloading. Such delays can be minimized if vehicles were aligned on two sides of the download submodule so that as one is being unloaded, the other vehicle can be moved into position. Nonetheless, other types of delays such as extended time between the arrival of convoys from the CSA can be anticipated. Assuming such delays will occur, it is apparent that the download submodule will still have some dead time that could be used for unloading other ammunition not requiring reconfiguration. The decision to use the download submodule for such work would be dependent on a number of factors such as: "How far away and what is the terrain like from the download submodule to the storage site where the ammunition is to be stored?" "Can the palletized ammunition be moved from the location of the download submodule to the storage site by roller conveyors, or must it be picked up by a conventional fork lift and moved to the storage site?" (See Figure 3). Comparisons of times required by each alternative need to be made. It may be better to drive the long haul transport vehicle directly to the storage site and offload it with conventional forklifts.

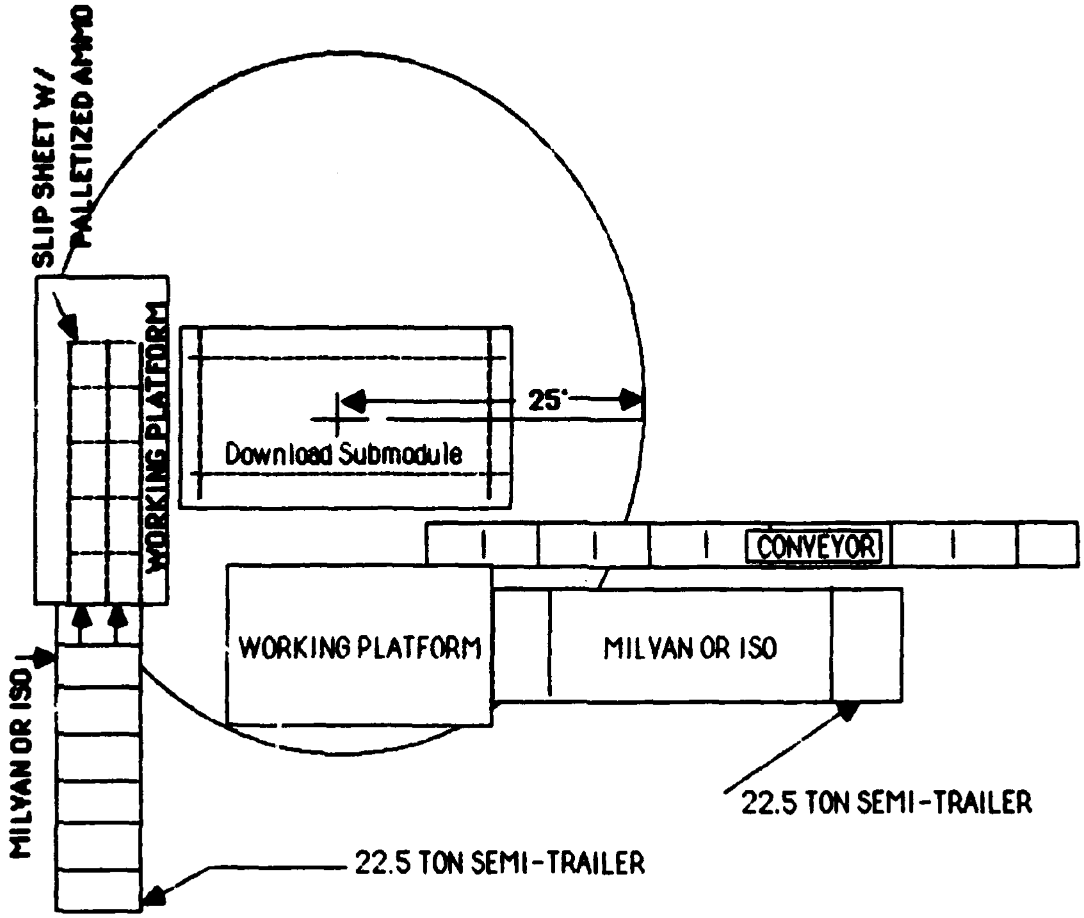

Figure 1 - Alternative Number 1: Download Submodule Workcell.

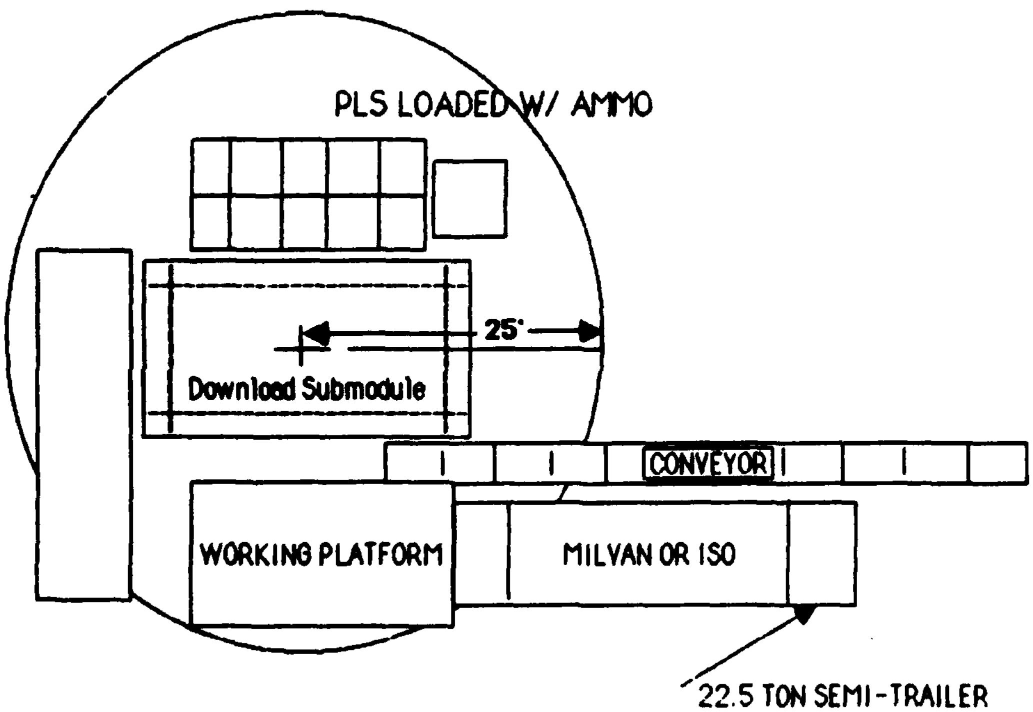

Figure 2 - Alternative Number 2: Download Submodule Workcell.

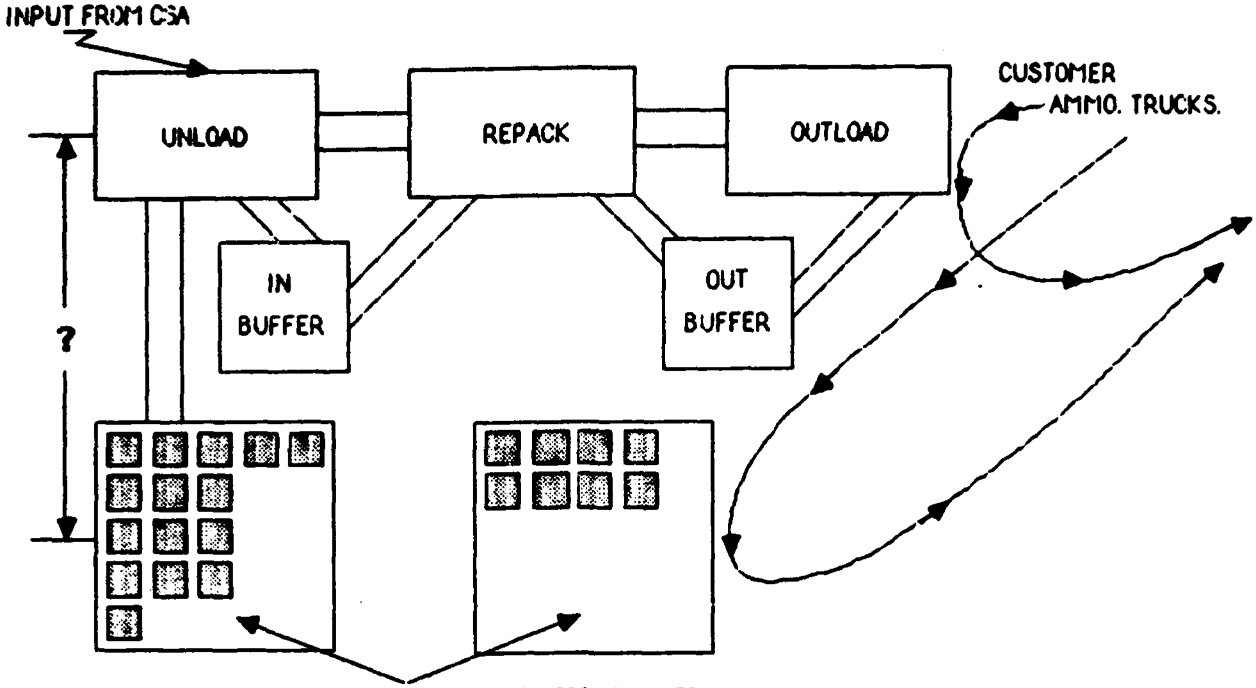

Figure 3 - Basic Configuration of an Ammunition Reconfiguration Module (ARM).

Although it is not within the scope of this study to fully explore these various alternatives in depth, they are mentioned as a reminder to the reader that such alternatives are possible. Decisions as to whether they should be implemented are dependent on the exigencies of the situation.

2. Sorting Submodule - The detailed concept of operations for the sorting submodule has not yet been defined in terms of sorting ammunition requiring repackaging versus ammunition not requiring repackaging. However, this is not considered to be a key consideration in this study. In the least complicated design mode, the sorting submodule would automatically move the palletized ammunition from the conveyor where it had been placed by the downloading submodule, and queue it in position to be handled by the repackaging submodule, i.e., one line for changing the artillery projectiles from a wholesale package to a readyround ammunition container (RAC) and a parallel line for changing 105 tank rounds and 4.2" mortar rounds from a wholesale package to a RAC. If the queuing area is not large enough to accommodate all of the ammunition from the unloading submodule, then the sorting module would have to move the ammunition to a buffer storage area where it could be held temporarily and then recycled by the sorter into the repackaging queuing area as required, or recycled via conventional fork lifts. Under either condition, it is apparent that the cycle rate of the sorting submodule should equal that of the unloading module in order to avoid a bottleneck situation occurring between the downloading submodule and the sorting submodule. The operating envelope of the sorting submodule is dependent on whether or not the conveyor rollers leading to the buffer storage area and repackaging submodules are powered or not. If the sorting submodule were visualized as sitting beside a turntable, the envelope for the sorting (pushing) arm should be slightly less than the diameter of the turntable. As shown in Figure 4, the diameter could be as small as 70 inches in accommodate the largest pallet or as large as 12 ft to accommodate several pallets on the turntable at the same time. The practical size would perhaps be in the neighborhood of eight ft in diameter so it could be transported without disassembly on the bed of the truck. See schematic at Figure 4.

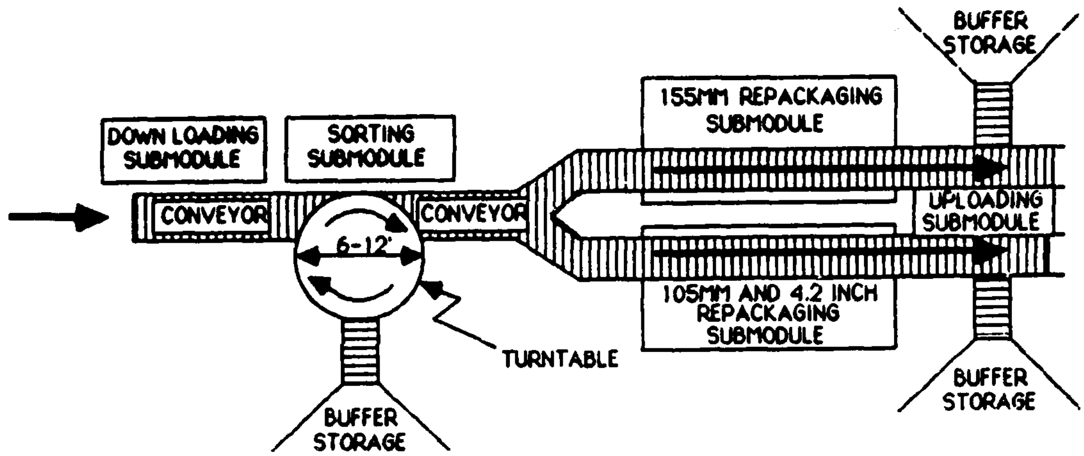

Figure 4 - Sorting and Repackaging Submodules.

3. Repackaging Submodules - The repackaging operation is visualized as two separate submodules operating in parallel lines. Figures 5, 6, and 7 are schematics of the 155mm repackaging submodule as designed by the U.S. Army Tooele Depot.

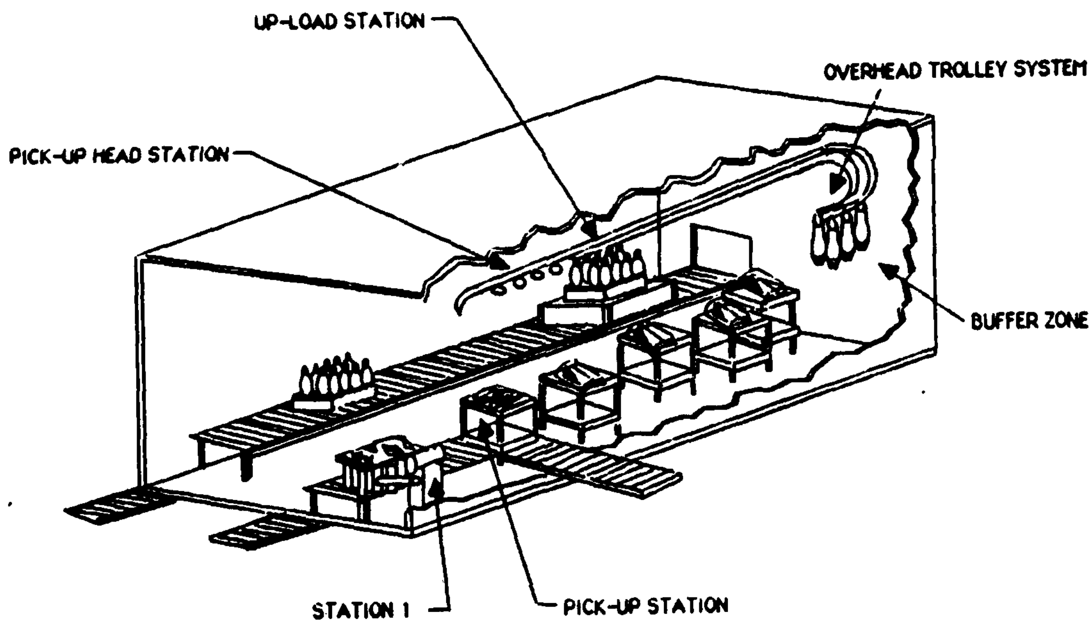

Figure 5 - Sketch of Conceptual 155mm Projectile Repackaging Submodule.

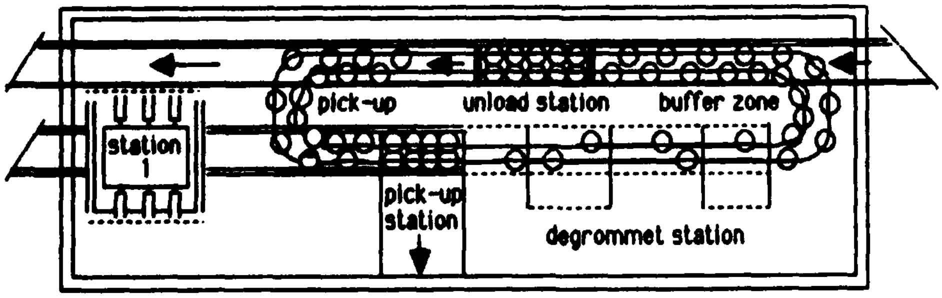

Figure 6 - 155mm Artillery Projectile Repackaging Submodule Floor Plan.

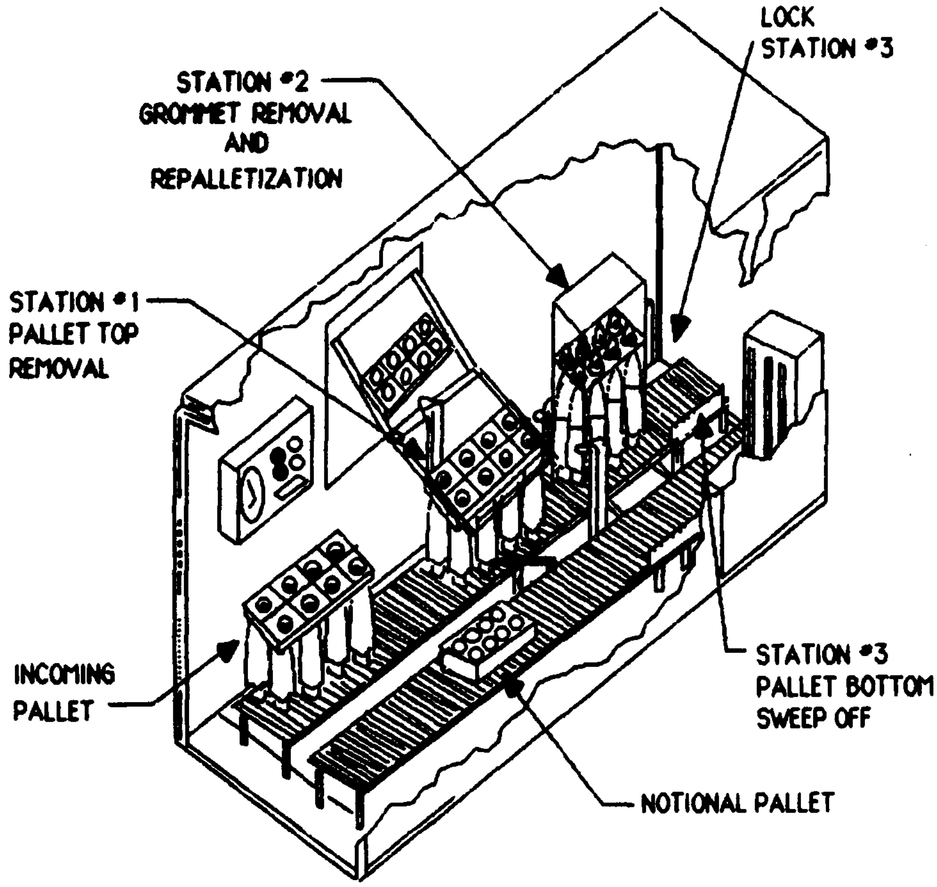

Figure 7 - 155mm Artillery Projectile Repalletizing System.

Sketches are not available for the repalletizing system for 105mm tank and 4.2 inch mortar rounds. This system would be required to:

- Remove a box of ammunition from a pallet.
- Open the box and remove the fiber tubes from the box.
- Open (cut) the fiber tubes and extract the bare round from the fiber tube.
- Place the bare round in the Readyround Ammunition Container (RAC).
- Discard the scrap materiel (box, fiber tubes, banding material and pallet when empty).

NOTE: A prototype was designed by the FMC Corporation which could be mounted on a vehicle or trailer the approximate size of a five ton truck.

Table 5 shows the required total number of rounds that must be repacked in order to issue 486.9 ST of 155mm, 366.4 ST of 105mm and 216.7 ST of 4.2 inch mortar rounds per 24 hours. These quantities are representative of an ASP issuing a total of 1500 ST of ammunition per day which is the quantity used as the baseline in this study. As shown in Figure 4, it is visualized that one line would repackage 155mm artillery shells and a separate line would repackage both 105mm tank rounds or 4.2 inch mortar rounds.

The requirement for this study is to determine the operating rates at which the two repack submodules must operate to meet the anticipated demand. If the ARM was able to operate as a "factory in the field", i.e., continuous feed into the repack submodules, no down time and continuous demand for the output, then the operating rate could be determined easily by dividing the rounds required by the time available:

$$\text{Repack Rate} = \frac{\text{Total Rounds Required}}{\text{Total Operating Time}}$$

However, using this formula would provide rates such as:

- 0.1015 Rounds per second.
- 6.0913 Rounds per minute.

These data are difficult to grasp, so a more meaningful calculation would be the time available per round, which is the the reciprocal of the Rate.

$$\text{Time Available} = \frac{\text{Total Operating Time}}{\text{Total Rounds Required}}$$

The "Time Available" will be defined as the "Unit Repack Time". As used in this definition, "unit" refers to one round, or "unit" of ammunition and is not associated with a combat "unit" such as a company, battery, battalion, etc.

This formula would provide much more meaningful results such as:

- 9.85 seconds per round.
- 4.06 seconds per round.

For example, the brigade that is used in this study requires the following rounds, based on an ARM issue of 1500 ST per 24 hours.

<u>Table 5 - Round Requirements, By Type of Ammunition, For Repackaging, Based on an ARM Total of 1500 ST Per Day.</u>

Type Ammo	Rounds/24 Hours
155 projectile	8775
105mm Tank	10992
4.2 inch	10281
105mm + 4.2 inch	21273

If the submodules operated continuously for 24 hours, the maximum allowable Unit Repack Times would be:

Table 6 - Unit Repack Times, By Type of Ammunition, Based on a 24 Hours Per Day Operation, to Issue 1500 ST Per Day.

Type Ammo	Unit Repack Times (Sec/Rnd)
155 projectile	9.85
105mm Tank	7.86
4.2 inch	8.40
105mm + 4.2 inch	4.06

Unfortunately, the ARM is not a "factory in the field". It is estimated that, at best, the ARM would only operate for 22 hours a day if it was not required to displace, and only 16 hours per day if a move is required. These reductions in time would require the following Unit Repack Times to meet the anticipated demand:

Table 7 - Unit Repack Times, By Type of Ammunition, Based on 22 and 16 Hours Per Day of ARM Operation.

Type Ammo	Unit Repack Times (Sec/Rnd)	
	22 Hours	16 Hours
155 projectile	9.03	6.56
105mm Tank	7.21	5.24
4.2 inch	7.70	5.60
105mm + 4.2 inch	3.72	2.71

D. Realistic Operating Rates

However, the realities of war are such that it is not reasonable to assume that the ARM will be able to operate continuously for either 16 or 22 hours. Other interruptions and delays can be anticipated, even though they are not specifically known. This means that the actual repack rates must be increased, (and the Unit Repack Time reduced), i.e., the machines must work faster when they are running, in order to meet the demand.

A series of trade-offs must be made to determine the actual required rates that will compensate for the undefined but anticipated delays. For example:

a. The stockage of unprocessed (wholesale pack) ammunition could be made quite large to preclude any stoppage due to an empty input hopper.

b. The stockage of repacked ammunition could be allowed to get quite large during periods of low demand to preclude stoppage due to an overly full output hopper.

c. The repack submodules could be made to operate quite fast so that a large quantity of ammunition would be repacked when the machines are actually operating.

Unfortunately, alternatives a. and b. defeat one of the purposes of the ARM which is to reduce the vulnerability of the forward ammunition issue facility by minimizing the stockage on the ground. In addition, the ARM is meant to be a mobile facility that can "rapidly" displace. Large stockage, in either the input and/or output hoppers, negates these purposes.

It is generally assumed that, with the type of machinery used to repackage artillery, tank and mortar ammunition, "faster is more expensive". Therefore, the repack submodules must operate fast enough to meet the demand, but not excessively fast which would drive up the cost and cause excessive idle time in the field. The analytical trick is to determine the required operating rates that will meet the anticipated demand without having machines that are excessively costly because they operate too fast, or require excessive input and/or output stockage.

The analytical methodology that best addresses this type of problem is "Queuing Theory".

E. Queuing Theory

Queuing theory deals with waiting in lines (queues) and service rates. It has wide application - from bank tellers to production lines to gas stations. Simple queuing models deal with "single-queue, single-server" situations. These problems are normally handled analytically. More complex situations involving "multiple queues and multiple servers" are often best handled using a computer model to simulate the process under study.

> NOTE: Doctor Stanley B. Gershwin of the Massachusetts Institute of Technology has addressed some of the "Production Line" problems associated with the ARM in his report, "Research In Advanced Manufacturing Systems". He suggests a Hierarchical Control Structure with three levels to schedule and control "tasks" and to exchange and coordinate information. Further, he proposes an "Assemble/Disassembly Network Methodology" for determining "optimal" machine production rates and storage buffer sizes. Dr. Gershwin's work may produce analytically developed insights into the problems associated with buffers and rates in the ARM, but is beyond the scope of this study.

Queuing theory usually starts with an expected arrival rate, or demands. In this study - demands for ammunition (five pallets per hour, ten ST per day, seven rounds per minute) are represented by the Greek letter Lambda (λ). The second variable associated with queuing theory is the expected service rate. In this study the service rate is the repack cycle rate required to meet these demands (eight rounds per minute, 17 ST per day, etc.) and is represented by the Greek letter Mu (μ).

The first basic law of queuing theory is that μ must be greater than λ; that is, the mean service rate must be faster than the mean demand rate, (we must repack rounds faster than the demand).

Another inherent assumption is that demands arrive randomly or stochasticly. For example, if the average arrival rate is five demands per hour, then the demand can arrive anytime within the hour, not one every 12 minutes. However, over a large sample, the average rate would be one demand every twelve minutes.

The service rate is also assumed to be stochastic. However, over a long period it will approach μ, the expected service rate.

In this study, both of these assumptions are valid. Although the ARM may exercise some influence over the arrival of customer convoys, the realities of war dictate that there will be randomness to the actual arrivals.

In this section of this study, lambda (λ) is the "Demand Rate". It represents the rate at which rounds are required in order to satisfy the anticipated demand.

> NOTE: In this case, it does NOT represent "Demand on the ASP" by the arrival of combat unit convoys at the ASP.

Lambda can be expressed as:

$$\frac{X_1 \text{ Rounds}}{24 \text{ Hours}}$$

$$\frac{X_2 \text{ Rounds}}{\text{Hour}}$$

$$\frac{X_3 \text{ Rounds}}{\text{Minute}} \text{, or}$$

$$\frac{X_4 \text{ Rounds}}{\text{Second}}$$

Mu is the "Service Rate". This is the actual rate at which rounds must be repackaged in order to meet the "Demand Rate". If we had a perfect "factory in the field", with no down time at all, then Mu, the repackaging production or "Service" rate could equal lambda, the Demand rate. However, this is not at all realistic and can never be achieved. Therefore, Mu must be greater than lambda, which meets the first rule of queueing theory expressed previously. Like lambda, Mu would also be expressed as:

$$\frac{\text{Rounds}}{\text{Time}}$$

In queuing theory, the ratio of lambda to mu (λ/μ) is very critical. The formula for the expected number of customers, or unsatisfied demands (in the ARM it would be the number of rounds waiting to be repacked) waiting for service (repacking) is:

$$\bar{n} = \frac{\lambda/\mu}{1 - \lambda/\mu} \text{ , } \frac{\lambda}{\mu} < 1$$

It can be seen that if $\lambda/\mu = 1$ then:

$$\bar{n} = \frac{1}{1-1} = \frac{1}{0} = \infty$$

This represents the "infinite queue". If λ/μ is very close to 1 then $\bar{n}$, or the waiting line, will be long. If it is 0.5, then the average number in the queue will be one and if $\lambda/\mu < 0.5$, the expected number in the queue will be less than one. However, for μ to get larger, causing λ/μ to get smaller, then the repacking machines must operate faster, which is assumed to be more expensive.

In ASI Report # 83-6, "Systems Analysis of The BRASS 2000 Concept" (Contract DAAK11-81-c-0085, Task Order #7) dated October 1983, we provided the details on an analysis of λ/μ as it pertains to the ARM. In this study it was determined that the ration of λ/μ should be in the range of 0.6 to 0.75.

Four "classic" queuing theory statistics were examined. These were:

- $\bar{n}$ - the expected number waiting in the queue for service.

$$\bar{n} = \frac{\lambda/\mu}{1-(\lambda/\mu)}, \quad \frac{\lambda}{\mu} < 1$$

- P_0 - the probability that zero items are waiting in the queue for service.

$$P_0 = 1-(\lambda/\mu), \quad \frac{\lambda}{\mu} < 1$$

- P_n - the probability that n (n = 1, 2 ...n) items are waiting in the queue for service.

$$P_n = (\lambda/\mu)n \quad x \quad (1-\lambda/\mu), \quad \lambda/\mu < 1, n = 1, 2 .. n$$

- $\bar{tw}$ - the average waiting time for an item in the queue waiting service.

$$\bar{tw} = \frac{1}{\mu-\lambda} - \frac{1}{\mu}, \quad \frac{\lambda}{\mu} < 1$$

It should be noted that three of the statistics ($\bar{n}$, P_0 and P_n) are independent of the absolute values of lambda and mu and are sensitive only to their ratio. However, the fourth, $\bar{tw}$ is sensitive to the absolute values of lambda and mu as well as their ratio.

Figures 8, 9, 10, and 11 show the characteristics of each of the four statistics as a function of the ratio of λ/μ. The statistic tw will be dependent on the absolute value of lambda and mu but will follow the form shown in figure 11.

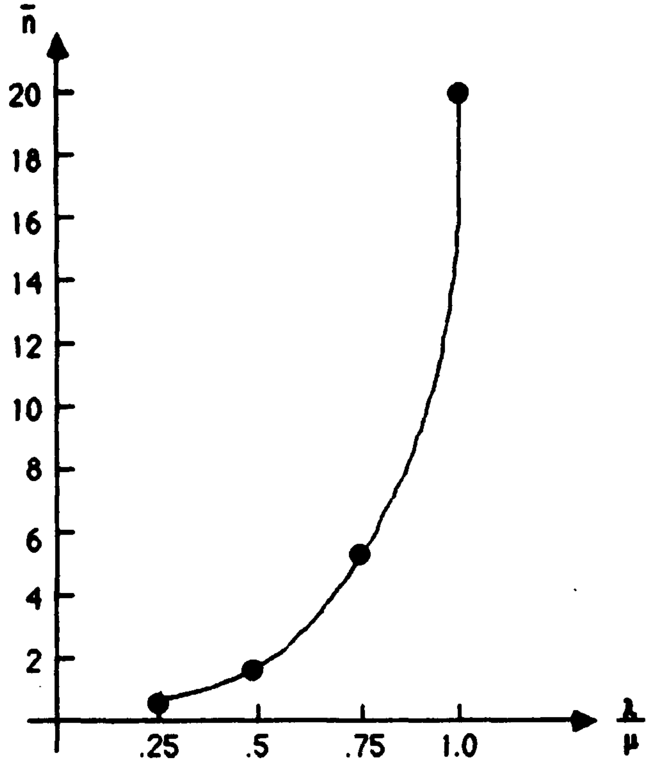

Figure 8 – n as a Function of $\frac{\lambda}{\mu}$.

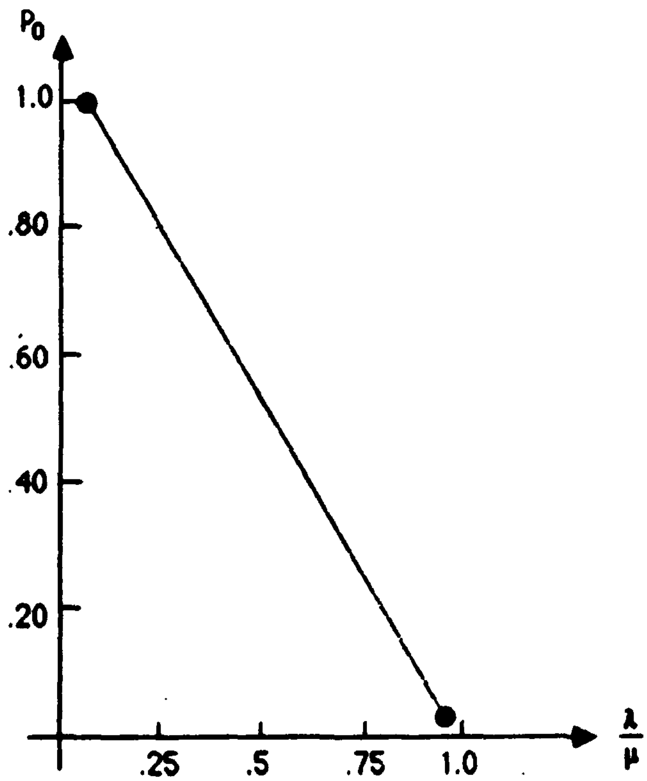

Figure 9 – P_0 as a Function of $\frac{\lambda}{\mu}$.

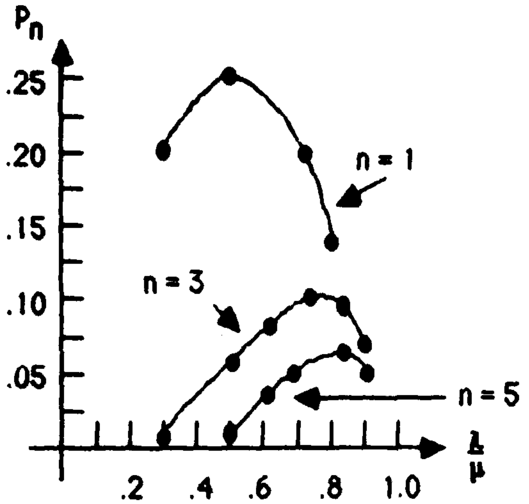

Figure 10 - P_n as a Function of $\frac{\lambda}{\mu}$.

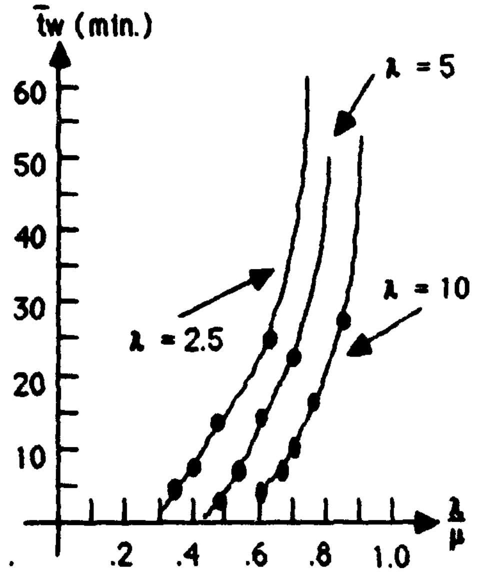

Figure 11 - $\bar{t}w$ as a Function of $\frac{\lambda}{\mu}$.

The relationship of $\bar{t}w$ to the absolute value of λ and μ is illustrated in Figure 12. Two plots are shown, each with a constant ratio of λ/μ. In the first, $\lambda/\mu = 0.60$. Three values of λ (0.3, 3, 30) and three values of μ (0.5, 5, 50) that would produce a constant ratio of $\lambda/\mu = 0.60$ were used. (Note: For the second plot, $\lambda/\mu = 0.75$. The three values used for λ were 0.3, 3 and 30 and for μ were 0.4, 4 and 40).

Given $\bar{t}w = \frac{1}{\mu-\lambda} - \frac{1}{\mu}, \frac{\lambda}{\mu} < 1$

λ/μ	λ	μ	tw
.60	0.3	0.5	3.0
.60	3.0	5.0	0.3
.60	30.0	50.0	0.03
.75	0.3	0.4	7.5
.75	3.0	4.0	0.75
.75	30.0	40.0	0.075

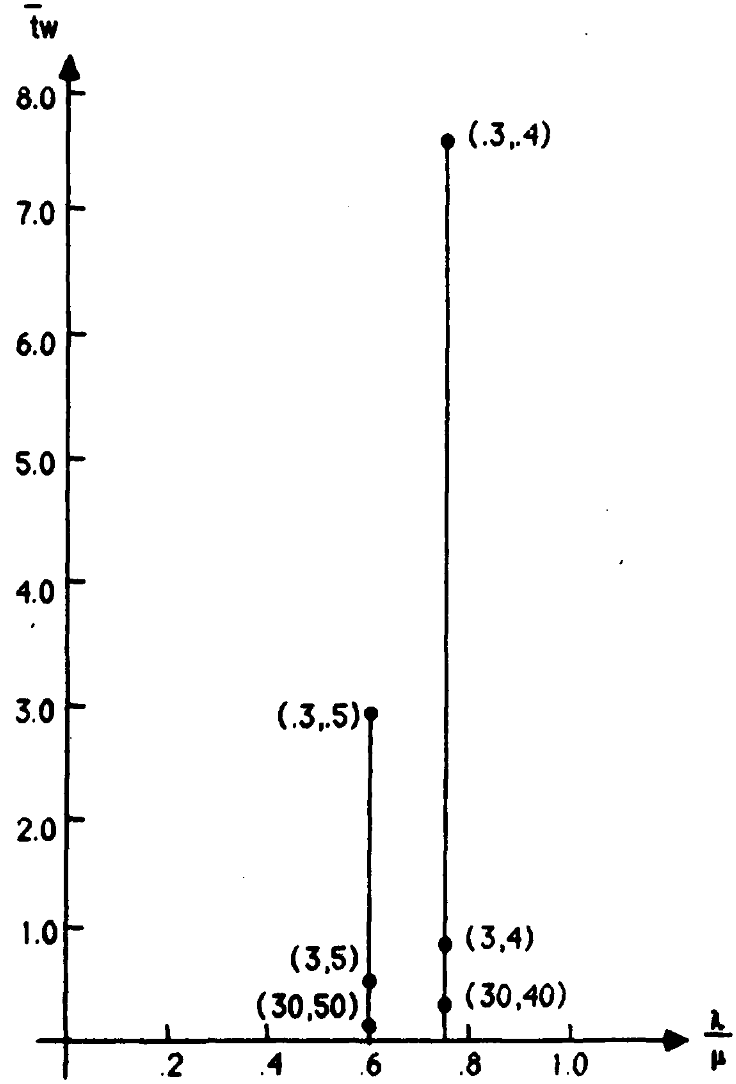

Figure 12 - Illustrations of The Sensitivity of $\bar{tw}$ To The Magnitudes of λ and μ, When The Ratio of λ/μ Remains Constant.

F. Queuing Theory Analysis of The Repack Submodule.

Having discussed the requirements of the Repack Submodule and having introduced queuing theory, this section will now apply queuing theory to gain further insights into the operating requirements of the Repack Submodule.

As shown earlier (in Table 5) the Repack Submodule is required to repack 155mm projectiles, 105mm tank rounds and 4.2 inch mortar rounds. The pallet and packing configuration of the artillery projectiles are significantly different from the tank and mortar rounds (which are packed in very similar manner). Therefore the Repack Submodule would actually have two separate operating lines, one for projectiles and one for the boxed ammunition (105mm and 4.2 inch) as shown in Figure 4.

In this study, 1500 ST per day has been the baseline case used for the ammunition that the notional brigade would expend. However, it is very reasonable to assume that this could vary ± 20% (300 ST). Thus, it is reasonable that this study looks at the effect of total demand requirements of 1200 ST, 1500 ST and 1800 ST per day, as shown in Tables 1, 2 and 3.

In our earlier discussions of the overall operation of the ASP/ARM it was recognized that the ASP/ARM would not always be operational for a full 24 hours per day. Realistically, each submodule would be down for maintenance, etc., at least two hours per day, and on some days the ASP/ARM would have to displace to an alternate location. Therefore, the cases in which the ASP/ARM is operating for 16 and 22 hours per day are also of interest.

In the previous discussion of queuing theory it was pointed out that the ratio of lambda to mu was critical. In queuing theory, the ratio of lambda to mu must be less than 1.0 ($\lambda/\mu < 1.0$). If we examine the case of $\lambda/\mu = 1.0$ analytically, we are actually looking at the ideal case that does not consider any of the random features of demand or service. It is the unrealistic case of the "perfect factory in the field". In looking at the Repack Submodule, the case of $\lambda/\mu = 1.0$ is the "best case", that is, the repack times available in that case represent the maximum times that would ever be available. These are the times shown in Tables 6 and 7.

Table 8 through 16 attempt to tie all of these cases/variables together. Each table examines the available repack times per round, per pallet and per ST for 155mm projectiles, 105mm tank rounds, 4.2 inch mortar rounds and 105mm and 4.2 inch rounds combined. Data are presented for a 22 hour work day and a 16 hour work day. Separate tables are presented for demands of 1200 ST per day, 1500 ST per day and 1800 ST per day. Lastly, each case is shown for $\lambda/\mu = 1.0$ (the ideal "best case"), $\lambda/\mu = 0.60$ and $\lambda/\mu = 0.75$.

Table 8 - Ammo Repack Times with Lambda/Mu = 1.00
1500 ST/DAY

Type of Ammo:	155 mm	105 mm	4.2 in	105mm + 4.2in
Expenditures				
* Rnds/day	8775.00	10992.00	10281.00	21273.00
* Pallets/day	1097.00	362.78	257.00	619.78
* Tons/day	486.88	366.41	216.69	583.10
Repack/hr (22 hr)				
* Rnds/hr	398.86	499.64	467.32	966.95
* Pallets/hr	49.86	16.49	11.68	28.17
* Tons/hr	22.13	16.66	9.85	26.50
Repack/min (22hr)				
* Rnds/min	6.65	8.33	7.79	16.12
* Pallets/min	0.83	0.27	0.19	0.47
* Tons/min	0.37	0.28	0.16	0.44
Min/repack (22hr)				
* Min/rnd	0.15	0.12	0.13	0.06
* Min/pallet	1.20	3.64	5.14	2.13
* Min/ton	2.71	3.60	6.09	2.26
Sec/repack (22hr)				
* Sec/rnd	9.03	7.21	7.70	3.72
* Sec/pallet	72.20	218.31	308.17	127.79
* Sec/ton	162.67	216.15	365.50	135.83
Repack/hr (16hr)				
* Rnds/hr	548.44	687.00	642.56	1329.56
* Pallets/hr	68.56	22.67	16.06	38.74
* Tons/hr	30.43	22.90	13.54	36.44
Repack/min (16hr)				
* Rnds/min	9.14	11.45	10.71	22.16
* Pallets/min	1.14	0.38	0.27	0.65
* Tons/min	0.51	0.38	0.23	0.61
Min/repack (16hr)				
* Min/rnd	0.11	0.09	0.09	0.05
* Min/pallet	0.88	2.65	3.74	1.55
* Min/ton	1.97	2.62	4.43	1.65
Sec/repack (16hr)				
* Sec/rnd	6.56	5.24	5.60	2.71
* Sec/pallet	52.51	158.77	224.12	92.94
* Sec/ton	118.30	157.20	265.82	98.78

Table 9 - Ammo Repack Times with Lambda/Mu = 1.00
1200 ST/DAY

Type of Ammo:	155 mm	105 mm	4.2 in	105mm + 4.2in
Expenditures				
* Rnds/day	7020.00	8793.60	8224.80	17018.40
* Pallets/day	877.60	290.22	205.60	495.82
* Tons/day	389.50	293.13	173.35	466.48
Repack/hr (22 hr)				
* Rnds/hr	319.09	399.71	373.85	773.56
* Pallets/hr	39.89	13.19	9.35	22.54
* Tons/hr	17.70	13.32	7.88	21.20
Repack/min (22hr)				
* Rnds/min	5.32	6.66	6.23	12.89
* Pallets/min	0.66	0.22	0.16	0.38
* Tons/min	0.30	0.22	0.13	0.35
Min/repack (22hr)				
* Min/rnd	0.19	0.15	0.16	0.08
* Min/pallet	1.50	4.55	6.42	2.66
* Min/ton	3.39	4.50	7.61	2.83
Sec/repack (22hr)				
* Sec/rnd	11.28	9.01	9.63	4.65
* Sec/pallet	90.25	272.89	385.21	159.73
* Sec/ton	203.34	270.19	456.87	169.78
Repack/hr (16hr)				
* Rnds/hr	438.75	549.60	514.05	1063.65
* Pallets/hr	54.85	18.14	12.85	30.99
* Tons/hr	24.34	18.32	10.83	29.16
Repack/min (16hr)				
* Rnds/min	7.31	9.16	8.57	17.73
* Pallets/min	0.91	0.30	0.21	0.52
* Tons/min	0.41	0.31	0.18	0.49
Min/repack (16hr)				
* Min/rnd	0.14	0.11	0.12	0.06
* Min/pallet	1.09	3.31	4.67	1.94
* Min/ton	2.46	3.28	5.54	2.06
Sec/repack (16hr)				
* Sec/rnd	8.21	6.55	7.00	3.38
* Sec/pallet	65.63	198.47	280.16	116.17
* Sec/ton	147.88	196.50	332.27	123.48

Table 10 - Ammo Repack Times with Lambda/Mu = 1.00
1800 ST/DAY

Type of Ammo:	155 mm	105 mm	4.2 in	105mm + 4.2in
Expenditures				
* Rnds/day	10530.00	13190.40	12337.20	25527.60
* Pallets/day	1316.40	435.34	308.40	743.74
* Tons/day	584.26	439.69	260.03	699.72
Repack/hr (22 hr)				
* Rnds/hr	478.64	599.56	560.78	1160.35
* Pallets/hr	59.84	19.79	14.02	33.81
* Tons/hr	26.56	19.99	11.82	31.81
Repack/min (22hr)				
* Rnds/min	7.98	9.99	9.35	19.34
* Pallets/min	1.00	0.33	0.23	0.56
* Tons/min	0.44	0.33	0.20	0.53
Min/repack (22hr)				
* Min/rnd	0.13	0.10	0.11	0.05
* Min/pallet	1.00	3.03	4.28	1.77
* Min/ton	2.26	3.00	5.08	1.89
Sec/repack (22hr)				
* Sec/rnd	7.52	6.00	6.42	3.10
* Sec/pallet	60.16	181.93	256.81	106.49
* Sec/ton	135.56	180.13	304.58	113.19
Repack/hr (16hr)				
* Rnds/hr	658.13	824.40	771.08	1595.48
* Pallets/hr	82.28	27.21	19.28	46.48
* Tons/hr	36.52	27.48	16.25	43.73
Repack/min (16hr)				
* Rnds/min	10.97	13.74	12.85	26.59
* Pallets/min	1.37	0.45	0.32	0.77
* Tons/min	0.61	0.46	0.27	0.73
Min/repack (16hr)				
* Min/rnd	0.09	0.07	0.08	0.04
* Min/pallet	0.73	2.21	3.11	1.29
* Min/ton	1.64	2.18	3.69	1.37
Sec/repack (16hr)				
* Sec/rnd	5.47	4.37	4.67	2.26
* Sec/pallet	43.76	132.31	186.77	77.45
* Sec/ton	98.59	131.00	221.51	82.32

Table 11 - Ammo Repack Times with Lambda/Mu = 0.60
1500 ST/DAY

Type of Ammo:	155 mm	105 mm	4.2 in	105mm + 4.2in
Expenditures				
* Rnds/day	8775.00	10992.00	10281.00	21273.00
* Pallets/day	1097.00	362.78	257.00	619.78
* Tons/day	486.88	366.41	216.69	583.10
Repack/hr (22 hr)				
* Rnds/hr	664.77	832.73	778.86	1611.59
* Pallets/hr	83.11	27.48	19.47	46.95
* Tons/hr	36.88	27.76	16.42	44.17
Repack/min (22hr)				
* Rnds/min	11.08	13.88	12.98	26.86
* Pallets/min	1.39	0.46	0.32	0.78
* Tons/min	0.61	0.46	0.27	0.74
Min/repack (22hr)				
* Min/rnd	0.09	0.07	0.08	0.04
* Min/pallet	0.72	2.18	3.08	1.28
* Min/ton	1.63	2.16	3.65	1.36
Sec/repack (22hr)				
* Sec/rnd	9.03	7.21	7.70	3.72
* Sec/pallet	72.20	218.31	308.17	127.79
* Sec/ton	162.67	216.15	365.50	135.83
Repack/hr (16hr)				
* Rnds/hr	548.44	687.00	642.56	1329.56
* Pallets/hr	68.56	22.67	16.06	38.74
* Tons/hr	30.43	22.90	13.54	36.44
Repack/min (16hr)				
* Rnds/min	9.14	11.45	10.71	22.16
* Pallets/min	1.14	0.38	0.27	0.65
* Tons/min	0.51	0.38	0.23	0.61
Min/repack (16hr)				
* Min/rnd	0.11	0.09	0.09	0.05
* Min/pallet	0.88	2.65	3.74	1.55
* Min/ton	1.97	2.62	4.43	1.65
Sec/repack (16hr)				
* Sec/rnd	6.56	5.24	5.60	2.71
* Sec/pallet	52.51	158.77	224.12	92.94
* Sec/ton	118.30	157.20	265.82	98.78

Table 12 - Ammo Repack Times with Lambda/Mu = 0.60
1200 ST/DAY

Type of Ammo:	155 mm	105 mm	4.2 in	105mm + 4.2in
Expenditures				
* Rnds/day	7020.00	8793.60	8224.80	17018.40
* Pallets/day	877.60	290.22	205.60	495.82
* Tons/day	389.50	293.13	173.35	466.48
Repack/hr (22 hr)				
* Rnds/hr	531.82	666.18	623.09	1289.27
* Pallets/hr	66.48	21.99	15.58	37.56
* Tons/hr	29.51	22.21	13.13	35.34
Repack/min (22hr)				
* Rnds/min	8.86	11.10	10.38	21.49
* Pallets/min	1.11	0.37	0.26	0.63
* Tons/min	0.49	0.37	0.22	0.59
Min/repack (22hr)				
* Min/rnd	0.11	0.09	0.10	0.05
* Min/pallet	0.90	2.73	3.85	1.60
* Min/ton	2.03	2.70	4.57	1.70
Sec/repack (22hr)				
* Sec/rnd	11.28	9.01	9.63	4.65
* Sec/pallet	90.25	272.89	385.21	159.73
* Sec/ton	203.34	270.19	456.87	169.78
Repack/hr (16hr)				
* Rnds/hr	438.75	549.60	514.05	1063.65
* Pallets/hr	54.85	18.14	12.85	30.99
* Tons/hr	24.34	18.32	10.83	29.16
Repack/min (16hr)				
* Rnds/min	7.31	9.16	8.57	17.73
* Pallets/min	0.91	0.30	0.21	0.52
* Tons/min	0.41	0.31	0.18	0.49
Min/repack (16hr)				
* Min/rnd	0.14	0.11	0.12	0.06
* Min/pallet	1.09	3.31	4.67	1.94
* Min/ton	2.46	3.28	5.54	2.06
Sec/repack (16hr)				
* Sec/rnd	8.21	6.55	7.00	3.38
* Sec/pallet	65.63	198.47	280.16	116.17
* Sec/ton	147.88	196.50	332.27	123.48

Table 13 - Ammo Repack Times with Lambda/Mu = 0.60
1800 ST/DAY

Type of Ammo:	155 mm	105 mm	4.2 in	105mm + 4.2in
Expenditures				
* Rnds/day	10530.00	13190.40	12337.20	25527.60
* Pallets/day	1316.40	435.34	308.40	743.74
* Tons/day	584.26	439.69	260.03	699.72
Repack/hr (22 hr)				
* Rnds/hr	797.73	999.27	934.64	1933.91
* Pallets/hr	99.73	32.98	23.36	56.34
* Tons/hr	44.26	33.31	19.70	53.01
Repack/min (22hr)				
* Rnds/min	13.30	16.65	15.58	32.23
* Pallets/min	1.66	0.55	0.39	0.94
* Tons/min	0.74	0.56	0.33	0.88
Min/repack (22hr)				
* Min/rnd	0.08	0.06	0.06	0.03
* Min/pallet	0.60	1.82	2.57	1.06
* Min/ton	1.36	1.80	3.05	1.13
Sec/repack (22hr)				
* Sec/rnd	7.52	6.00	6.42	3.10
* Sec/pallet	60.16	181.93	256.81	106.49
* Sec/ton	135.56	180.13	304.58	113.19
Repack/hr (16hr)				
* Rnds/hr	658.13	824.40	771.08	1595.48
* Pallets/hr	82.28	27.21	19.28	46.48
* Tons/hr	36.52	27.48	16.25	43.73
Repack/min (16hr)				
* Rnds/min	10.97	13.74	12.85	26.59
* Pallets/min	1.37	0.45	0.32	0.77
* Tons/min	0.61	0.46	0.27	0.73
Min/repack (16hr)				
* Min/rnd	0.09	0.07	0.08	0.04
* Min/pallet	0.73	2.21	3.11	1.29
* Min/ton	1.64	2.18	3.69	1.37
Sec/repack (16hr)				
* Sec/rnd	5.47	4.37	4.67	2.26
* Sec/pallet	43.76	132.31	186.77	77.45
* Sec/ton	98.59	131.00	221.51	82.32

Table 14 - Ammo Repack Times with Lambda/Mu = 0.75
1500 ST/DAY

Type of Ammo:	155 mm	105 mm	4.2 in	105mm + 4.2in
Expenditures				
* Rnds/day	8775.00	10992.00	10281.00	21273.00
* Pallets/day	1097.00	362.78	257.00	619.78
* Tons/day	486.88	366.41	216.69	583.10
Repack/hr (22 hr)				
* Rnds/hr	531.82	666.18	623.09	1289.27
* Pallets/hr	66.48	21.99	15.58	37.56
* Tons/hr	29.51	22.21	13.13	35.34
Repack/min (22hr)				
* Rnds/min	8.86	11.10	10.38	21.49
* Pallets/min	1.11	0.37	0.26	0.63
* Tons/min	0.49	0.37	0.22	0.59
Min/repack (22hr)				
* Min/rnd	0.11	0.09	0.10	0.05
* Min/pallet	0.90	2.73	3.85	1.60
* Min/ton	2.03	2.70	4.57	1.70
Sec/repack (22hr)				
* Sec/rnd	9.03	7.21	7.70	3.72
* Sec/pallet	72.20	218.31	308.17	127.79
* Sec/ton	162.67	216.15	365.50	135.83
Repack/hr (16hr)				
* Rnds/hr	548.44	687.00	642.56	1329.56
* Pallets/hr	68.56	22.67	16.06	38.74
* Tons/hr	30.43	22.90	13.54	36.44
Repack/min (16hr)				
* Rnds/min	9.14	11.45	10.71	22.16
* Pallets/min	1.14	0.38	0.27	0.65
* Tons/min	0.51	0.38	0.23	0.61
Min/repack (16hr)				
* Min/rnd	0.11	0.09	0.09	0.05
* Min/pallet	0.88	2.65	3.74	1.55
* Min/ton	1.97	2.62	4.43	1.65
Sec/repack (16hr)				
* Sec/rnd	6.56	5.24	5.60	2.71
* Sec/pallet	52.51	158.77	224.12	92.94
* Sec/ton	118.30	157.20	265.82	98.78

Table 15 - Ammo Repack Times with Lambda/Mu = 0.75
1200 ST/DAY

Type of Ammo:	155 mm	105 mm	4.2 in	105mm + 4.2in
Expenditures				
* Rnds/day	7020.00	8793.60	8224.80	17018.40
* Pallets/day	877.60	290.22	205.60	495.82
* Tons/day	389.50	293.13	173.35	466.48
Repack/hr (22 hr)				
* Rnds/hr	425.45	532.95	498.47	1031.42
* Pallets/hr	53.19	17.59	12.46	30.05
* Tons/hr	23.61	17.77	10.51	28.27
Repack/min (22hr)				
* Rnds/min	7.09	8.88	8.31	17.19
* Pallets/min	0.89	0.29	0.21	0.50
* Tons/min	0.39	0.30	0.18	0.47
Min/repack (22hr)				
* Min/rnd	0.14	~~0.11~~	0.12	0.06
* Min/pallet	1.13	3.41	4.82	2.00
* Min/ton	2.54	3.38	5.71	2.12
Sec/repack (22hr)				
* Sec/rnd	11.28	9.01	9.63	4.65
* Sec/pallet	90.25	272.89	385.21	159.73
* Sec/ton	203.34	270.19	456.87	169.78
Repack/hr (16hr)				
* Rnds/hr	438.75	549.60	514.05	1063.65
* Pallets/hr	54.85	18.14	12.85	30.99
* Tons/hr	24.34	18.32	10.83	29.16
Repack/min (16hr)				
* Rnds/min	7.31	9.16	8.57	17.73
* Pallets/min	0.91	0.30	0.21	0.52
* Tons/min	0.41	0.31	0.18	0.49
Min/repack (16hr)				
* Min/rnd	0.14	0.11	0.12	0.06
* Min/pallet	1.09	3.31	4.67	1.94
* Min/ton	2.46	3.28	5.54	2.06
Sec/repack (16hr)				
* Sec/rnd	8.21	6.55	7.00	3.38
* Sec/pallet	65.63	198.47	280.16	116.17
* Sec/ton	147.88	196.50	332.27	123.48

Table 16 - Ammo Repack Times with Lambda/Mu = 0.75
1800 ST/DAY

Type of Ammo:	155 mm	105 mm	4.2 in	105mm + 4.2in
Expenditures				
* Rnds/day	10530.00	13190.40	12337.20	25527.60
* Pallets/day	1316.40	435.34	308.40	743.74
* Tons/day	584.26	439.69	260.03	699.72
Repack/hr (22 hr)				
* Rnds/hr	638.18	799.42	747.71	1547.13
* Pallets/hr	79.78	26.38	18.69	45.07
* Tons/hr	35.41	26.65	15.76	42.41
Repack/min (22hr)				
* Rnds/min	10.64	13.32	12.46	25.79
* Pallets/min	1.33	0.44	0.31	0.75
* Tons/min	0.59	0.44	0.26	0.71
Min/repack (22hr)				
* Min/rnd	0.09	0.08	0.08	0.04
* Min/pallet	0.75	2.27	3.21	1.33
* Min/ton	1.69	2.25	3.81	1.41
Sec/repack (22hr)				
* Sec/rnd	7.52	6.00	6.42	3.10
* Sec/pallet	60.16	181.93	256.81	106.49
* Sec/ton	135.56	180.13	304.58	113.19
Repack/hr (16hr)				
* Rnds/hr	658.13	824.40	771.08	1595.48
* Pallets/hr	82.28	27.21	19.28	46.48
* Tons/hr	36.52	27.48	16.25	43.73
Repack/min (16hr)				
* Rnds/min	10.97	13.74	12.85	26.59
* Pallets/min	1.37	0.45	0.32	0.77
* Tons/min	0.61	0.46	0.27	0.73
Min/repack (16hr)				
* Min/rnd	0.09	0.07	0.06	0.04
* Min/pallet	0.73	2.21	3.11	1.29
* Min/ton	1.64	2.18	3.69	1.37
Sec/repack (16hr)				
* Sec/rnd	5.47	4.37	4.67	2.26
* Sec/pallet	43.76	132.31	186.77	77.45
* Sec/ton	98.59	131.00	221.51	82.32

The best (most time available) of the realistic cases (i.e., $\lambda/\mu < 1.0$) is the case shown in the top half (22 hours) of Table 15. The total demand is 1200 ST and $\lambda/\mu = 0.75$. The worst case is the bottom half (16 hours) of Table 13. The total demand is 1800 ST and $\lambda/\mu = 0.60$. Tables 11 and 14 represent the range of the expected operating environment and should be used in developing the basic operational requirements for the Repack Submodule of the ASP/ARM.

Given the subjectiveness of the input data used in this analysis, the data presented in tables 8 through 16 should be interpreted as "providing insight, trends and boundaries" as opposed to absolute values. However, these data do indicate that, in order to satisfy a nominal demand, the repack submodule must be capable of repacking one 155mm Artillery projectile at least every five seconds and either one 105mm tank or 4.2 inch mortar round at least every two seconds. These requirements will present significant challenges to the designer. The alternative is to have additional repack submodules in the ASP/ARM so that parallel lines are available.

G. Queuing Theory Analysis of The Upload Submodule

With this discussion of queuing theory as a base, an examination of the upload submodule will be made. The Upload Submodule performs similar but opposite tasks than the download submodule. It will be required to pick up Readyround Ammunition Containers (RACs) from either the ground or a platform and place them on a combat unit's trucks.

> NOTE: In this study it is assumed that a RAC will be approximately the same size and weight as the current logistics pallet. The reduction in packaging material in the RAC will be compensated for by the increased weight of the material in the empty RAC. This assumption is necessary as there are no RACs available to measure.

A single RAC will contain only one type of ammunition. Table 17, shows the type of trucks available and ammunition the customer units would pick up.

Table 17 - Truck and Ammunition Type For Each Type Battalion Receiving Repackaged Ammunition.

		TYPE OF AMMUNITION		
TYPE BN	TYPE OF TRUCK	105mm	4.2 In.	155mm Projectile
TANK	10 TON	YES	YES	NO
MECH. INF.	5 TON	NO	YES	NO
ARTILLERY	10 TON	NO	NO	YES

It is further assumed that:

- The RACs for 105mm and 4.2 inch ammunition would be very similar in size and weight.
- Trucks in the tank battalion convoys may be loaded with:

- All tank ammunition.
- All mortar ammunition.
- A mix of some tank and some mortar ammunition.

It should be amplified that only the RACs containing the repackaged 105 mm and 4.2 rounds and 155 mm projectiles will be loaded by the upload submodule. The other ammunition will be uploaded at or near the field storage location (See sketch at Figure 3) by conventional Rough Terrain Forklifts (RTFLs). The loading of this ammunition, which represents less than 30% of the brigade's total, will not be discussed further in this report.

The base case that has been discussed is the case in which the ARM is required to issue 1500 ST of ammunition in 24 hours. However, as with the repack submodule, it is unrealistic to assume that the outload submodule will be able to operate for a full 24 hours without interruption. Therefore, two other cases will be examined; 22 hours per day and 16 hours per day. The 16 hours would be indicative of the operating time available when the ARM must displace (move) to a new location.

In addition to looking at these two operating times, two other rates will be examined. Twelve hundred ST for the brigade per day of demand would represent a day at the low end of the spectrum. Reduced demand could be caused by weather, operating posture (defense vs offense), mission priority, restricted supply rates, etc. On the other end of the sepectrum, 1800 ST per day would represent surge conditions.

The required time, for the developmental item that will eventually be the outload submodule, to <u>unload</u> a pallet weighing one ST or less, from a flat bed trailer to a roller platform, is 20 seconds per cycle. As the weight of the pallet increases, up to a maximum of two ST, the allowable cycle time increases up to a maximum of 45 seconds. Therefore, these two cycle time values, 20 and 45 seconds, plus a mid-value of 30 seconds per cycle will be examined.

If the brigade is being issued 1500 ST of ammunition per day, then 1070 ST will require repacking. This figure drops to 856 ST per day if the issue total is only 1200 ST per day and goes up to 1284 ST per day if surge conditions exist and the brigade requires 1800 ST per day. (The reader is reminded that the outload submodule is only concerned with that ammunition that has been repacked).

If the brigade is receiving 1070 ST of repacked ammunition, then the combat battalions will send 35 convoys per day, totaling 116 Trucks, of which 98 will be ten ton trucks and 18 will be five ton trucks. Thus the "Average Truck" will require 9.2 ST to load it. (NOTE: These data were extracted from ASI Report 85 - 10 "Wargaming Analysis of Ammunition Flow Rates", which was mentioned in the preface to this report).

Average truck load =

$$\frac{[(98 \text{ Trucks} \times 10 \text{ ST/Truck}) + (18 \text{ Trucks} \times 5 \text{ ST/Truck})]}{116 \text{ Trucks}} = 9.22 \ \frac{\text{ST}}{\text{Truck}}$$

The average convoy will consist of 3.3 trucks (116 trucks ÷ 35 convoys = 3.3 trucks/convoy).

If the average load per truck is 9.22 ST, and assuming the average lift for the outload submodule is one ST, then each "Average Truck" would require 9.22 cycles. At a cycle rate of 20 seconds (= 3 Lifts per minute), it would require 3.06 minutes to load each truck.

$$\left(9.2 \frac{ST}{Truck} \div 3 \frac{ST}{Minutes}\right) = 3.06 \frac{Minutes}{Truck}$$

The total time required to load an average convoy of 3.3 trucks, at 3.06 minutes per truck is 10.13 minutes per convoy.

This same logic can be used for each case as the load cycle rate and total tonnage requirements vary.

With these data, the values of lambda and mu can be calculated, and with lambda and mu known, the various queuing theory statistics can be calculated.

As discussed above, lambda (λ) represents the rate at which customers (Combat Unit Convoys) arrive for service. (NOTE: This is different than the lambda used earlier in the analysis of the repack submodule). Thus:

$$\lambda = \frac{\text{Total Convoys}}{\text{Operating Hours}} = \frac{\text{35 Convoys}}{\text{22 Hours}} = \frac{\text{1.6 Convoys}}{\text{Hour}}$$

Mu is a measure of the Service Rate, that is, the time required to load one convoy.

$$\mu = \frac{\text{Load Time}}{\text{Convoy}}$$

NOTE: Lambda and mu must be in the same units (Event/Time Unit). Since lambda is in convoys per hour, mu must be expressed in the same unit. Therefore, mu, as used in this section of the study is calculated by dividing 60 Minutes/Hour by the average time required to load the average convoy.

$$Mu = 60 \frac{\text{Minutes}}{\text{Hour}} \div 10.13 \frac{\text{Minutes}}{\text{Convoy}} = 5.9 \frac{\text{Convoys}}{\text{Hour}}$$

Once lambda and mu have been established, then the queuing theory statistics can be calculated. In dealing with the outload submodule, we will calculate:

$\bar{n}$ = The expected number of convoys waiting to be serviced (loaded).

P_0 = The Probability that zero convoys are waiting to be serviced.

P_n = (N = 1, 2, 3, 4). The probability that n convoys are waiting to be serviced.

$\bar{tw}$ = The average waiting time (in hours) for a convoy that is in the queue.

$\bar{T}$ = The total time (in hours) a convoy is in the ARM, waiting plus being serviced.

$(\bar{T} = \bar{tw} + \bar{ts})$.

Each of these statistics will be calculated for 18 different cases. The variables that establish these cases are:

- Total ST Issued: 1200 ST, 1500 ST and 1800 ST.
- ARM Operating Hours: 16 and 22 hours.
- Cycle Rate: 20, 30 and 45 seconds.

Table 18 displays the results of these calculations.

Figures 13, 14, 15 and 16 illustrate the relationship of selected outload submodule operating variables and the computed queuing theory statistics.

Table 18 - Reconfigured Ammunition Unloading Times and Expected Convoy Queuing Delays

TOTAL TONS PER 24 HR	TONS REPAC PER 24 HR	OPERATING HRS PER DAY	LOAD CYCLE RATE (SEC)	NO OF CONVOYS/DAY	NO OF 10 T TRKS	NO OF 5 T TRKS	TOTAL NO OF TRKS	AV. TIME LOAD TRK (MIN)	AV. TIME LOAD CONVOY (MIN)	λ	μ	$\frac{\lambda}{\mu}$	$1-\frac{\lambda}{\mu}$	$\bar{n}$	P_0	P_1	P_2	P_3	P_4	$\bar{t_w}$	$\bar{t_s}$	$\bar{T}$
1500	1070	22	20	35	98	18	116	3.06	10.13	1.6	5.9	27	.73	.37	.73	20	.05	01	004	.06	.17	.23
1500	1070	22	30	35	98	18	116	4.6	15.15	1.6	4.0	.4	.6	67	.60	24	.10	.04	.02	.17	.25	.42
1500	1070	22	45	35	98	18	116	6.9	22.74	1.6	2.64	.61	.39	1.54	.39	24	.14	09	05	.58	.38	.96
1500	1070	16	20	35	98	18	116	3.06	10.13	2.2	5.9	.37	.63	.59	.63	.23	.09	.03	.01	.10	.17	.27
1500	1070	15	30	35	98	18	116	4.6	15.15	2.2	4.0	.55	.45	1.22	.45	.25	.14	.07	.04	.31	.25	.56
1500	1070	16	45	35	98	18	116	6.9	22.74	2.2	2.64	.83	.17	4.99	.17	.14	.12	.10	.08	1.89	.38	2.27
1200	856	22	20	28	78	14	92	3.06	10.13	1.3	5.9	22	.78	.28	.78	.17	04	.01	.002	.05	.17	.22
1200	856	22	30	28	78	14	92	4.6	15.15	1.3	4.0	.33	67	.48	.68	.22	.07	.02	.01	.12	.25	.37
1200	856	22	45	28	78	14	92	6.9	22.74	1.3	2.6	.50	.50	1.0	.50	.25	.13	.06	.03	.38	.38	.77
1200	856	16	20	28	78	14	92	3.06	10.13	1.8	5.9	.30	.70	.42	.70	.21	06	.02	.01	.07	.17	.24
1200	856	16	30	28	78	14	92	4.6	15.15	1.8	4.0	.44	.56	.78	.56	.25	.11	.05	.02	.20	.25	.44
1200	856	16	45	28	78	14	92	6.9	22.74	1.8	2.6	.67	.33	2.06	.33	22	.15	.10	.07	179	.38	1.18
1800	1284	22	20	42	118	22	140	3.06	10.13	1.91	5.9	.32	.68	.48	.68	.22	.07	.02	.01	.08	.17	.25
1800	1284	22	30	42	118	22	140	4.6	15.15	1.91	4.0	.48	.52	.91	.52	.25	.12	.06	.03	.23	.25	.48
1800	1284	22	45	42	118	22	140	6.9	22.74	1.91	2.6	.73	.27	2.77	.27	.19	.14	.11	.08	1.06	.38	1.45
1800	1284	16	20	42	118	22	140	3.06	10.13	2.63	5.9	.45	.55	.80	.55	.25	.11	.05	.02	.14	17	.31
1800	1284	16	30	42	118	22	140	4.6	15.15	2.63	4.0	.66	.34	1.92	.34	.22	.15	.10	.06	.48	.25	.73
1800	1284	15	45	42	11d	22	140	6.9	22.74	2.63	2.6	.996	.004	194	.005	.005	.005	.005	.005	73.6	.38	74.0

LEGEND

$\lambda = \frac{\text{TOTAL CONVOYS}}{\text{OPERATING HOURS}}$

$\mu = \frac{60\ \text{MIN}}{\text{HR}} \div x\ \frac{\text{MIN}}{\text{CONVOY}}$

x = the time required to load one convoy.

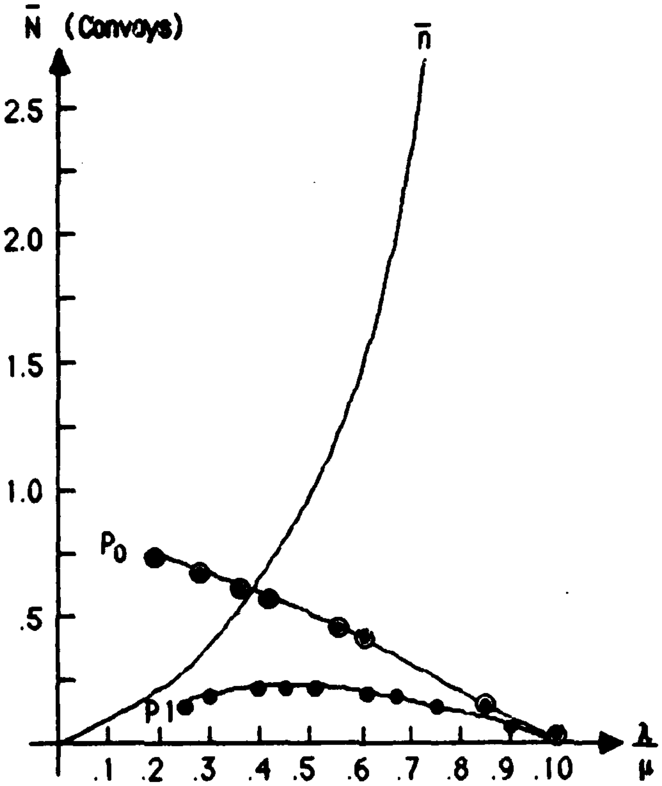

Figure 13 - $\bar{N}$, P_0 and P_1 as a Function of $\frac{\lambda}{\mu}$.

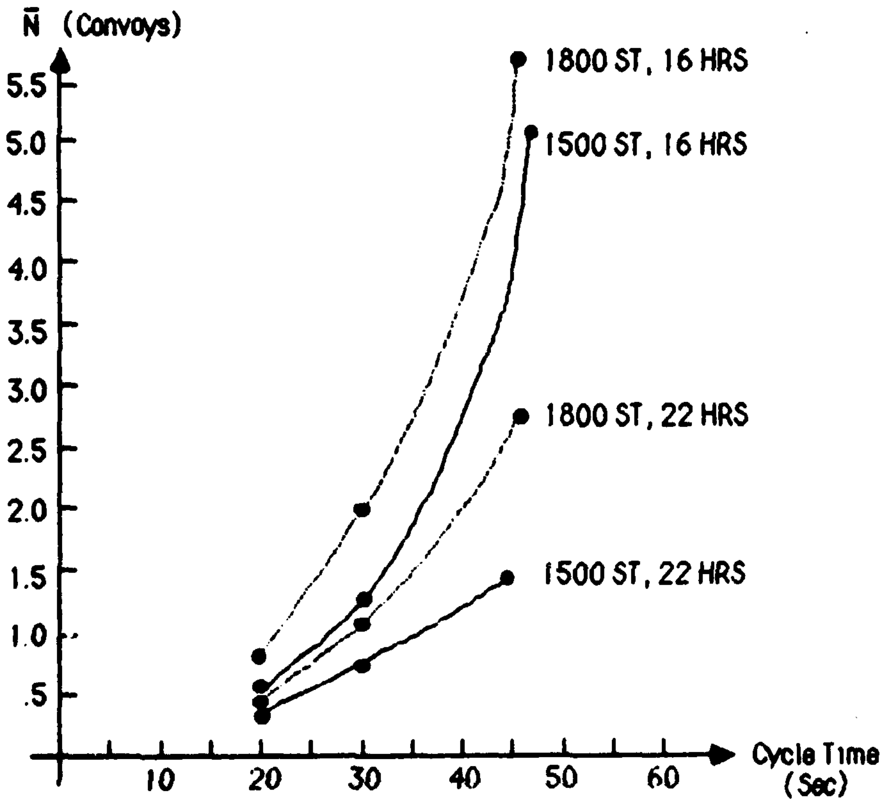

Figure 14 - $\bar{N}$ as a Function of Cycle Time and Tonnage.

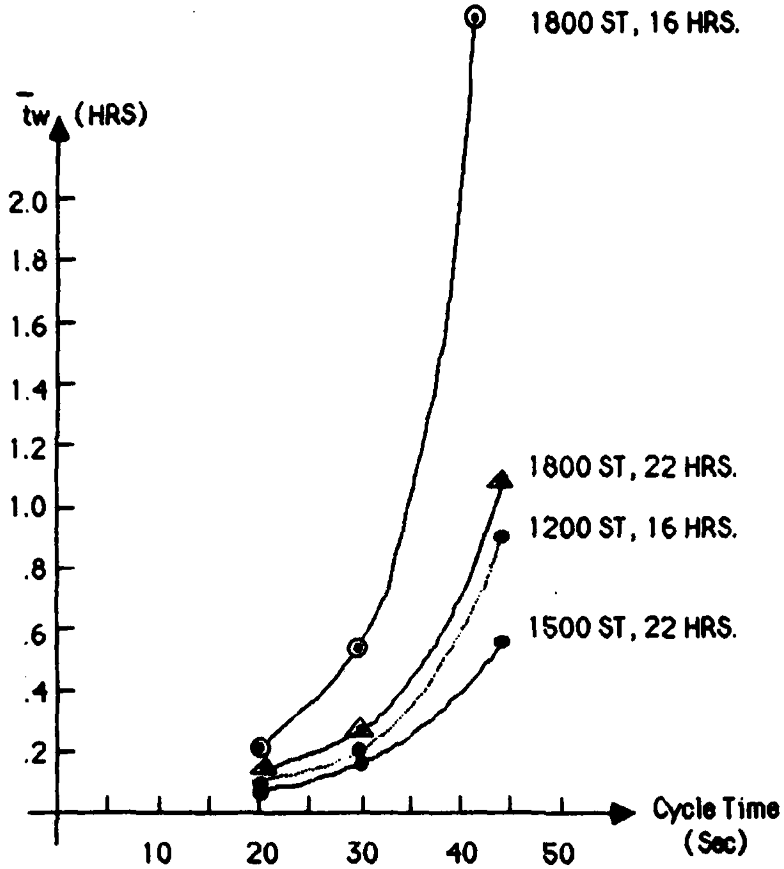

Figure 15 - $\overline{tw}$ as a Function of Cycle Time and Tonnage.

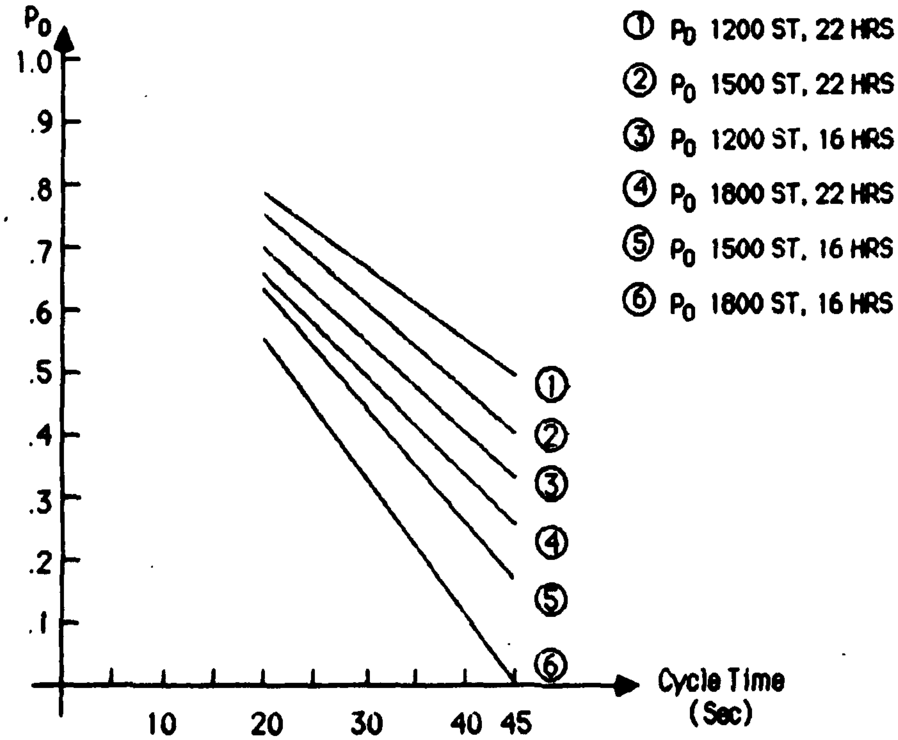

Figure 16 - P_0 as a Function of Cycle Time and Tonnage.

Table 18 and Figures 13 through 16 provide several insights into the operation of the outload submodule. The expected condition of issuing 1500 ST per day, requires outloading 1070 ST of repacked ammunition. This would require an average of 35 convoys per day. The submodule should be able to meet the requirements, even if the ASP/ARM displaces and there are only 16 hours available for operations. Only if the cycle time averages 45 seconds per cycle does the ratio of λ/μ exceed 0.75 and caution must be taken. If the demand is reduced 20% to 1200 ST per day, there are obviously no problems. However, if surge conditions exist and the brigade requires 1800 ST of ammunition, then the situation becomes much more sensitive. If 22 hours are available, then the ratio of λ/μ stays under 0.75, but it approaches 0.75 if the cycle rate is 45 seconds. However, if the ASP/ARM displaces, then there are only 16 hours available for operations. If the cycle rate is 45 seconds all of the trucks will probably not get loaded. In fact, if the cycle time exceeds an average of 35 seconds, the system is in jeopardy, as the ratio of λ/μ will exceed 0.75. Figures 13 and 14 show what happens to the expected number of convoys waiting for service as a function of λ/μ (Figure 13) and as a function of cycle time (Figure 14). Figure 15 illustrates how waiting time ($\bar{t}w$) increases with cycle time. Lastly, Figure 16 shows the decrease in P_0 and thus the increase in P_n, $n > 0$ (See Figure 10) as the cycle time increases.

H. Disposal of Scrap Material in an ASP/ARM

A major concern of any ASP/ARM commander operating in a forward area of a battlefield will be the handling and disposal of scrap material generated by reconfiguring the high volume, high density ammunition such as the 155mm projectiles, 105mm tank rounds and the 4.2 inch mortar from their wholesale packaging to a "readyround" ammunition container (RAC). If the situation permits, the scrap material can be transported to a safe distance from the ASP/ARM and burned. However, the burning of the scrap material creates a signature that can be seen for many miles by an enemy. It is also labor intensive to move the scrap material and to burn it. A second alternative is to bury it or grind it up and bury it. This requires the services of some type of grinding and earth moving equipment and is time consuming and labor intensive. This operation also provides an increased signature for an enemy to observe and thus determine the location of an ASP/ARM.

> NOTE: In many foreign countries the local nationals will haul away the scrap for free just to get the wood. However, since tactical security may preclude this option, the following information is presented.

Table 19 provides a summary of the quantities of scrap material that can be expected to accumulate during a 24-hour period of operation of an ASP/ARM. That is issuing 1500 ST of ammunition per day. The information contained in Table 19 is based on a notational brigade consuming of 1500 ST of ammunition per 24-hour period. The scrap material is generated by reconfiguring the 155mm projectiles, 105mm tank and 4.2 inch mortar ammunition. An additional, relatively small quantity of scrap material will be generated by the preparation of mixed pallets of small caliber ammunition, which is not included in Table 19. By weight, scrap is 99+% a combination of wood, particle board and paper. However, each pallet of 105mm and 4.2 inch mortar ammunition also generates four each 16-18 foot long steel bands for a total of 2184 bands (34,944 linear feet). Each 155mm pallet generates two bands six feet long for an additional 2222 bands totaling 13,332 linear feet. Thus, in one day, the ASP/ARM would need to dispose of almost 250 ST of burnable material plus 4400 steel bands equaling 48,276 linear feet or 9.14 miles.

Table 19 - Scrap Generated By a Typical ASP/ARM During a 24-Hour Period.

Type Ammo	24 Hour Total Demand (Tons)	*Wt/Pallet (Lbs.)	Number of Pallets	*Lbs. scrap per Pallet	Total scrap (Lbs.)	Total scrap (Tons)
155mm Proj.	458	873	1111	40	44,400	22.22
105mm Tank	344	1728	423	738	312,174	156.00
4.2" Mortar	216	3468	123	1140	140,200	70.11
					496,794	248.33

*Source: WARS Report RCS-CSGLD 1322 (RI)
Part 1-C, 30 Sept 1983.

Under current operations ammunition is issued to the combat units in its wholesale shipping configuration. The scrap material is generated in the combat unit's areas where the problem is even more critical as labor is of a greater premium and the signature left by the scrap material in the forward combat area is of even greater consequence.

As can be seen from the above, it is apparent that the disposal of scrap material generated by the operation of an ASP/ARM in a forward area represents a formidable problem, the resolution of which should be given priority attention. Current technology provides the capability to rapidly shred such materials to reduce the volume.

> NOTE: If the wood boxes and fiber containers from one ASP/ARM issuing 1500 ST per day were shredded they would completely fill twenty 8 x 8 x 20 foot MILVAN or ISO containers each day. Other technology applications may provide less labor intensive/time consuming solutions.

V FINDINGS

1. Fourteen types of ammunition and propellant consisting of the 155mm projectiles, 155mm propellant, 105mm tank rounds, 4.2 inch mortar round, TOW, DRAGON and STINGER missiles, 66mm, 40mm, 25mm, 50 caliber, 45 caliber, 7.62mm and 5.56mm will satisfy the primary recurring demands of a typical brigade (See Table 1).

2. Ammunition to be reconfigured from the wholesale packaging to a ready-for-use tactical package is the 155mm projectile, 105mm tank round and the 4.2 inch mortar. These three rounds represent 70.2% of the total daily tonnages normally flowing through an ASP/ARM (See Table 1).

3. Items to be issued in the same configuration in which they are received generally consist of the 155mm propellant, 66mm round, TOW, DRAGON, and STINGER missiles, and the small caliber ammunition such as the 40mm, 25mm, 50 caliber, 7.62mm and 5.56mm rounds.

4. Ammunition to be repalletized into a mixed load consists primarily of the 40mm and small caliber ≤ 50 caliber. Slightly different mixes are required for a tank company versus a mechanized infantry company versus a field artillery battery. It is not feasible to prepare a mixed pallet for an engineer company (See Table 4).

5. The cycle rate of 20 seconds for the download submodule of an automated ARM is dictated primarily by the objective of having an ARM operational within a period of two hours after arrival at a new site. Operating at this rate, the download submodule will experience dead time that could be utilized for downloading ammunition not requiring repackaging. Several factors must be considered before executing such an alternative.

6. The cycle rate for the sorting submodule will depend on the final design and assigned functions of the submodule, the concept for which has not been fully developed as of the time of this study. As a general rule, the cycle time of the sorting submodule should be directly correlated with that of the downloading submodule to preclude "bottlenecks" from occurring between the download submodule and the sorting submodule.

7. The cycle rate for the 155mm repackaging submodule in support of a heavy brigade, in a mid-intensity European scenario, is about five seconds per round based on a 22 hour operating day, or an eight round pallet every 40 plus seconds. Based on a 16 hour operating day, a round would be required to be processed about every four seconds or a pallet every 25 seconds.

8. Based on the same scenario as indicated in Finding 7. above, the 105mm line would require a cycle rate of five seconds based on a 22 hour work day, and 3.5 seconds based on a 16 hour work day.

9. Under the same conditions as indicated in Findings 7 & 8 above, the cycle rate for the 4.2 inch mortar would be five plus seconds based on a 22 hour work day and about four seconds based on a 16 hour work day.

10. If the 105mm and 4.2 inch rounds were both required to be repackaged using the same repackaging line (as visualized by the original concept), the cycle rate per round would be increased to about 2.5 seconds based on a 22 hour work day and less than two seconds based on a 16 hour work day.

11. The design of the uploading submodule will be similar to that of the download submodule, with the exception of the design of the end effector. This will be influenced by the final design of the readyround ammunition container (RAC). Therefore, the cycle rate of 20 seconds is suggested. If this is not achievable, a cycle rate of 35 seconds or less, as a maximum, would still be a workable alternative.

12. Scrap material generated as a result of reconfiguring ammunition from its wholesale package to a tactical package, from a single day's operation will total almost 250 ST of burnable material (wood, particle board and paper) and approximately 48,276 linear feet (9.14 miles) of steel banding material. Disposing of this material will present major problems in the Reconfiguration Module.

VI CONCLUSIONS

1. The Ammunition Reconfiguration Module (ARM), with four submodules, can operate in the vicinity of the Ammunition Supply Point (ASP) to support a brigade that requires approximately 1500 ST of Ammunition per 24 hours.

2. From a design and engineering point of view, the repacking submodule presents the greatest challenge as the times available to repackage rounds are restrictive, particularly if the ASP/ARM displaces and only 16 hours per day are available. This is also the only submodule whose operations can not be augmented. The other three submodules (Unload, Sort and Outload) can be augmented with conventional forklifts should the workload exceed the capabilities of the submodule machinery. However, if the workload warrants, a second repack submodule can be inserted in the ARM.

3. The queuing theory analysis of the submodules tends to integrate the randomness of the battlefield and adds credence to the results.

4. The problem associated with disposing of the scrap material caused by repacking is a major problem that must be considered.

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